THE COLLOIDAL STATE

OF THE

BLOOD SERUM

AND

ITS ELECTRICAL REACTIONS.

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The investigation of the blood serum from any particular point of view is always a difficult matter. There is apt to be the personal equation and one is very easily biassed by theories on such a subject At the start of this paper it is desired to make clear that one would lay down a distinct line between theory and fact. When one has given the result of investigations,one hopes that,even though few,they may be a contribution to the observations already made. In order to fulfil the purpose of the paper as a whole,which is to attempt to direct interest towards the colloidal state of the blood serum in relation to abnormal body conditions,it has been necessary to go fairly thoroughly into other theories and teachings on the subject. To do so has of necessity brought one to form one's own theories as well,and to criticise the views of others. To theorise is always a danger,but it sometimes assists towards the finding of the ultimate true cause of a reaction. One cannot hope that one's theories will prove acceptable in their entirety to any but oneself,and in dealing with such a new subject on which opinion is altering so frequently, one quite acknowledges that even oneself in the course of further investigations will alter one's own theories or at least modify them. To do that is the only scientifically honest way to attain real solutions. This paper,therefore,puts forward certain facts which are the result of much careful work,and then,by comparisons with the teaching and thoughts of others,endeavours to reach a reasonable theory which will fit in with the facts,and by using which one may proceed both to practical medicine and to further discovery.

Originally it was intended to investigate merely the behaviour of blood serum under electrical action,but it was realised after working for a period at this that to present even a partially adequate view of the serum,the investigation must be carried further and the other properties studied,both through one's own work and that of

others. Even in this somewhat lengthy, as it seems to me, discussion, one feels one has merely presented a few thoughts that open out a field of great interest and possibilities. I first became interested in the matter in the examination of syphilitic serum from primary sores and in reading about colloidal drugs, and have entered upon investigations in an endeavour to satisfy myself as to the reality of any foundation on which others build the claim for the use of these drugs.

The more one has investigated the serum both as a colloidal system and in disease conditions the more one is impressed with its variations and the greater is one's eagerness to find the cause. The action of drugs, apart from local action, must be due to their circulation in some form or other, or to the circulation of part or the whole of their dissociation products in the blood. eg. Sodium salicylate and its almost specific action in acute rheumatism, or the action on the heat centres of Quinine. Even that well acknowledged fact makes one suspect that there must be some actual effect in the blood which enables the changed state of the blood to affect the diseased region and the system as a whole. That there is this change with certain drugs we know, and later I hope to produce evidence in support which I am accumulating at present, but to do this here is outside the scope of this paper, which is merely, as it were, the introduction to the subject, and which may stimulate interest in the question.

In the first place, it is impossible to split the blood into different constituents. The blood system must be treated ultimately as a whole, and, as Matthews emphasises, not only does this include the blood corpuscles, plasma, lencocytes and platelets, but also the endothelial lining, and in my opinion the organs of the body generally. The effect, for example of the nervous system in profoundly altering the general body system including the blood is known. The effect again

of, say, hypnotic suggestion in treatment generally,[14] or in altering the condition of the skin and causing the effusion of serum is known. Yet, so great is the scope of these reactions that only a small section can be investigated at the one time, and it is undoubtedly in the great systems that we must look for the causes and effects which result in what we call symptoms as a whole, especially in what are defined as systemic diseases e.g. syphilis. Therefore, this paper is no attempt to lay to the account of the serum, as some writers do e.g. McDonagh[11], the responsibility for all conditions whatsoever present as symptoms, following of course on causal organisms in many cases. Rather it is written to suggest that the serum is a great factor in the control of the manifestations of health and disease, that its alteration is likely in most conditions and that it may be a valuable indicator of the variation from normal of an individual. The present advance in serum treatment of all descriptions, and such phenomena as Anaphylaxis[11], indicate the extreme importance of the blood. Further, transfusion experiments, when done at the front without previous testing of the bloods of the individuals concerned have occasionally showed that the blood in different individuals may vary so greatly as to cause a marked reaction. One, therefore, deals with only a part of this extremely important system with reluctance, yet there is sufficient data to show that even the serum itself is of great moment to the body as a whole and the circulating system as a part. Analogies are always dangerous, but the consideration of alterations in the serum and the cause may give one grounds for considering whether other body reactions are not dependent on a similar cause or even on the change in the circulating system itself.

Two great advances in science have shed great light on body reactions. The one is the discovery and study of the colloidal state of certain substances, both so-called semi-solids and liquids. The other is the development of the Electron Theory.

Both require to be considered for the purposes of this paper. It seems to me that often by the consideration of the investigations carried out in other spheres of science than medicine, one may often find much information which may be logically and profitably applied to medicine. In this investigation, therefore, I have turned for my original information to men who are not physiologists, but who are physico-chemists. A certain amount of information can be found in physiological works, but far more can be got from these other works.

The only point at issue is as to how far physico-chemical investigations can be applied to living tissues. In relation to the colloid state this is possible, for it is a state common both to serum and to many other forms of solution. It is a state common to Protoplasm, as Mathews points out, and to many other semi-solids outside the body. While inorganic bodies may show this state when in solution, they are farther removed in conduct from living tissues.

As one ascends in the scale one reaches a series of organic compounds of a complex nature and finds how closely they correspond in the state they are in to these body tissues, and one can then apply the findings of physico-chemists to reactions of these tissues.

As I will show, the findings of Ostwald and others from investigations on complex dyes and other bodies, can be repeated in blood serum, and thus a great source of information is opened to us.

The Electron Theory[5] is almost universally accepted in its main points. It is coming largely into acceptance as a practical explanation of many obscure facts. In some parts of it, it really ceases to be a theory, and proves facts. It is an accumulation of experiences and the summed up interpretation of these over a long period of time. Phenomena like XRays and the modification of the spectrum of the light from a Sodium flame by an electro-magnet were only explicable on the basis of such a theory. Radium and other such substances further advanced its claims. We in this

paper assume it and merely give the bare outline of the facts found through it in as far as they concern us.

The electron is a particle of negative electricity. There is no proof at present of a particle of positive electricity. Every atom consists of a centre of"positive"electricity with a certain number of electrons attached to it and revolving round it at a tremendous speed. In addition,these atoms may have attached to them one or two additional electrons or they may loose one or two on occasion. The number of electrons depends on the valency of the element in question. When there is a balance between the negative electrical charge due to the electrons attached and the positive electricity,the atom is neutral. When the electrons are more,the atom is negatively charged,and when less the atom is positively charged. In other words,positive and negative merely indicates the removal from or addition to the atom of one,two or more electrons according to the valency of the atom in question. Further,normally the atom is neutral,but when subjected to electrical force every atom has an additional one or more electrons attached to it,or loses one or more electrons from it .

Taking the atom of H,therefore,when positive it is an atom lacking one electron while the OH atom has attached to it an electron and is therefore negative. An ion therefore becomes a particle carrying an electric charge positive or negative.
If positive it is a positive atom i.e.an atom deprived of one or more electrons. If negative it may be an electron or an atom with one or two additional electrons,and whether positive or negative may be associated with more or less neutral matter.(Fournier) Broadly speaking,ions are usually therefore charged atoms. An electric current becomes a transference of electrons and therefore the real current is a current of negative electricity,composed of electrons. There is also a positive current of the much larger positive ions

but this can be neglected in relation to the real current. Similarly there is a movement of negative ions also neglected. These two movements, however, come into reckoning in a fluid and consequently will later come under notice in this paper, and the sum of these movements gives the total current, using the term widely, in a fluid.

We shall now turn to the consideration of the serum of the blood as a fluid in a colloid state. It is necessary, therefore, to consider the properties and reactions of this state in general, and especially as regards the particular type of colloid state in which the blood serum exists. No attempt has been made to give a resumé of text books. That is not necessary for this investigation, but it has been necessary to pick out those teachings and views which will enable one to present this paper as a logical whole, and to make clear the purpose and aim of the investigations. These, if one will be pardoned a personal note, had to be done and this paper written under the difficulties of life on a cruiser, and in off duty time. They were complicated by the need to invent one's own apparatus and by dependance on good weather and other circumstances to prevent failure from vibration etc. The final tests came after much experiment and those given followed on many adaptations and continued trials of apparatus. The investigation therefore was not so far-reaching as it might have been ashore, where additional experiments and testing of more findings of other authors for different colloidal substances might have been possible.

We turn now to a consideration of the colloidal state in which matter of most descriptions may be found.

The Colloid state may be said to be universal. The protoplasm in the cell is found to be in this condition, and in that special variety of it known as Gelation, a semi-solid substratum holding in its interstices the substances which are in true solution, such as

the extractives, salts and various other organic bodies (mathews). The substratum is composed of Proteins, Carbohydrates and Lipins linked in some manner with other substances, such as salts, which are also in the true solution.

The properties, to be discussed, of the Colloidal state show that the fundamental property of the state is its affinity for water and easy modification by salts, metabolic products, acids, anesthetics, drugs, enzymes etc."

The two great divisions of solutions, described by some, are crystalloids and colloids, the colloids being that variety which are usually" amorphous non-crystalline viscous (Κολλα=glue εἶδος=form) solutions which, when concentrated, set or gel and which do not dialyse through certain membranes." Although this was the original definition it has been found that under certain conditions substances found usually in colloidal state may crystallise e.g. haemoglobin, phycoerythrin, edestin, serum albumin, in which case the crystals are small and microscopic(Mathews). It thus becomes clear that colloidal solutions are substances in a certain state of solution. In other words the chemical constitution has nothing to do with the condition. The only relation between the chemical formula of the substance when in a colloidal state and that state is that the more complex the chemical constitution the more likely is the substance to be, usually, in a colloidal state.'

The fundamental fact about the colloidal state is, therefore, not the chemical constitution but the physical condition." The peculiar and distinctive properties of colloidal solutions are due to the larger size of the particles which are dispersed. Owing to this large size surface tension phenomena between solute and solvent come into play at the boundaries of the particles, and these phenomena which are lacking in ordinary solutions give to the colloidal solutions properties which ordinary solutions lack" (Mathews).

These particular phenomena referred to will be therefore considered in some detail for this reason:- The first point which it is desired to make clear in this paper is that the particles in question are, as it were, the important constituent of the fluid under consideration, and while alone they would be useless and the true solution is necessary, yet their properties and reactions with that solution are at the root of many of the reactions of the blood serum as a whole.

Colloids are usually physically heterogeneons liquids, i.e. they do <u>not</u> conform, as pure solutions do, to the following tests:-

(1) Susceptibility to hylotropic change.

(2) The hylotropic transformation taking place within narrow limits of Temperature and Pressure, and there being only one boiling and one coagulation temperature.

Such heterogeneous liquids can by changes in Temperature and Pressure be separated into at least two chemically different components. The blood serum is at once seen to correspond, in these respects at least, to this description of a colloidal liquid. It is necessary further to consider the general properties of such colloidal liquids, and it will be found, as is now noted in all physiological works, that blood serum is in all respects a colloidal liquid, possessing these general properties.

The optical properties of colloids are well known. They can be summed up as possessing Turbidity, a Tyndal cone on trans-illumination, and a "particular" appearance under the Ultramicroscope, the particles showing vibratory movement[1,2]. These properties can be easily verified personally.

They possess also mechanical properties in that they do not diffuse rapidly or to any great degree, nor do they dialyse through parchment membranes. One must qualify this by stating that they have been noticed to dialyse for a short period when in conjunction with

the molecularly dissolved phase, and further that the membrane must be suited to the size of the particles. If the particles are finely divided then a less porous membrane is required(Ostwald).

Some substances show, as is to be expected, intermediate forms, e.g. Congo red has a faint Tyndal cone, and dialyses very slightly through parchment(Ostwald).

Colloid solutions fall into two main divisions and in this paper the terminology of Ostwald is used in the discussion of these divisions and their differential properties. The two types are Suspensoids and Emulsoids, otherwise known as lyophobic (or hydrophobic) and lyophilic (or hydrophilic) solutions. The particular or so-called solid phase of the blood serum will be referred to as the Disperse Phase, while the medium in which the Disperse Phase exists will be called the Dispersion Means.

One can now give a simple differentation between the two types of colloids.

Special Colloid Analysis.(Ostwald).

Suspensoids.	Emulsoids.
(a) Viscosity not perceptibly greater than that of dispersion means.	(A) Viscosity substantially greater than that of dispersion means, even in low concentrations. Viscosity increases with lowering of temperature.
(b) Easily coagulable by electrolytes especially by salts with polyvalent ions.	(B) Difficultly coagulable by salts, which at times need to be added to saturation point to accomplish flocculation.

A rough example of (a) may be seen in testing the viscosity of Collosol silver in relation to water, when I found they were practical-ly the same.

It is to be noted that salts of the heavy metals frequently produce abnormal effects with regard to (B) (Ostwald). Later it will be seen that blood serum corresponds to the type Emulsoid, as do most organic substances in this state, such as gelatine and many aniline dyes.

The further point concerning the general properties of colloids is that they bear electrical charges, the particles showing a positive or negative condition in an electric field. This will be discussed later with a few experimental results.

The general electrical state, electro-positive or electro--negative, which is judged by the polarity of the particles, can be demonstrated by electrolytic methods, of which more later, by capillary analysis, and by the fact that in some cases colloids precipitate other colloids containing opposite charges.

We will now proceed to examine some of the general properties of colloids in detail. These to be dealt with first are surface phenomena between the surfaces of the Disperse Phase, hereafter referred to as D.P. and the Dispersion Means, to be referred to as D.M.

The D.P. made up, as it is, of so-called particles results in the creation of a series of surfaces, and a resultant total very large surface belonging to the material present as D.P.
For example, if one took a cube and subdivided it, it is obvious that there would be an enormous increase in the surface of the material of which the cube was made. A table will be quoted presently demonstrating this. Some writers go so far as to trace the whole of the reactions of a substance in colloidal state to alterations in the surface. Most of the considerations put forward are derived from Ostwald whose researches into the physico-chemical properties of the colloid state are the most extensive as far as I am aware. Other writers, when referred to, will be mentioned.

Theoretically there is a great possible variation in the phases of colloids. The system will vary accordingly. The D.P. may

be liquid solid or gaseous. The D.M.might also be in any of these conditions. The general definition of D.M.then becomes that it is the phase in excess. This is a point to be remembered when gelation comes to be considered. As far as the blood serum is concerned in its fluid state, the D.M.is the phase which is liquid, and the D.P.is the apparently solid phase.

The special peculiarity of colloids is that this type of system enables this great develcpement of surface between the two phases, and not only is the absolute surface very great, but the specific surface i.e.the relation of surface upon volume, is great also. This specific surface is called the Degree of Dispersion and its greatness is due to the particles being not only numerous but also present in a relatively small volume. There is the important additional fact that these particles are so distributed that the system is apparently homogeneous. Should coagulation set in, however, this even distribution ceases to exist and the particles aggregate. The gel state becomes thus the state of the substance when it is passing to or from a state of homogeneity.

The individual particles may be seen by the ultramicroscope. The intensity of the light undoubtably affects the number of particles seen.

The Pointolite lamp, for example, which is a tungsten arc, I believe, was found by me to show a much greater number of particles compared with a high powered Osram(60Watts). The size of the particles cannot be measured microscopically, according to Mathews, owing to the fact that, the illumination being indirect, there is a diffraction halo round them and it is not really the particle which is seen. Mathews further states that the particles can be centrifug-alised out, but Ostwald states that to all intents and purposes this is not so. Certainly one has noticed very little difference in the serum taken from a tube after standing and after centrifugalisation.

The individual particles vary in size in the same slide. This has been noted in case of Methyl Violet(Michaelis),and is quite evident in blood serum. The molecularly disperse phase i.e.the true solution or,in the case of fluid blood serum,the D.M.,may also vary in the size of the molecules. There is thus only an average dispersion value. These properties are present in polydispersoids,and protein solutions show ultrafiltration phenomena suggesting they are of this nature. The electric charge in the particles can be used to confirm this,as my experiments will show.

Although one cannot see the particles but only their halos, yet in extremes it is impossible to believe that the halos seen ultramicroscopically could belong to particles of the same size. Alteration of the mirror certainly alters the apparent size of the particles but the change occurs in all the particles in the field of the microscope in the same focus.

The change in the specific surface depending on the size of the particles and the number of particles now falls to be considered.

The degree of dispersion varies with changes in concentration, decreasing as the concentration increases. It further decreases with lowering of temperature. When the concentration reaches a critical point in a liquid $\frac{\text{D.M.}}{\text{D.P.}}$ liquid system,the droplets split into molecular droplets and the system becomes molecularly disperse.

The concentration $=\frac{\text{D.P.}}{\text{D.M.}}$ but above the critical point there is of course a reversal and the D.P.being in excess becomes by the previous definition the D.M. The greater the degree of subdivision of a liquid D.P.the nearer does it,that is,the particles or droplets, approximate to a solid in its mechanical behaviour e.g.it takes 4·5 atmosphere to squeeze 2μ oil globule through a tube of half its diameter. With the subdivision comes a tremendous increase in the surface energy of a given volume. Weimann on the other hand came to

the conclusion that solid particles become similar to liquid particles on subdivision.

Specific surface is made up, so to speak, of three forms thus:-

(1) $\frac{\text{Absolute surface of entire D.P.}}{\text{Total vol. of D.P.}}$

(11) $\frac{\text{Absolute surface of D.M.}}{\text{Total vol. of D.M.}}$

(111) $\frac{\text{Absolute surface of individual particle of the D.P.}}{\text{The vol. of the individual particle of the D.P.}}$

These three forms are present in a typical diphasic dispersoid. Whenever changes occur in the surface of that dispersoid, two of the above must change, while the three may. In colloids the third often varies with changes in concentration. It is obvious that when one reaches the finer degrees of subdivision in a molecular dispersoid, i.e. when one gets the ionic dissociation, the surface relationships become increasingly large, and true specific surface attains enormous value.

Turning now to the effect of subdivision both in terms of measurement and specific surface, the following table exemplifies the facts given above.

Changes in surface of a cube when subdivided (Ostwald).

Length of edge	No of cubes	Total surface	Specific surface.
1 cm	1	6 sq cm	6
1 mm ($1x10^{-1}$cm)	10^{3}	60 sq cm	6x10
1μ ($1x10^{-4}$cm)	10^{12}	60,000 sq cm	$6x10^{4}$
1$\mu\mu$ ($1x10^{-7}$cm)	10^{21}	6,000 sq m(*)	$6x10^{7}$
·001$\mu\mu$ ($1x10^{-10}$cm)	10^{30}	6 sq Km	$6x10^{10}$

(*) Ostwald has 6,000 sq cm which I take to be a printer's error)

Colloidal particles are defined as varying from ·1μ to 1$\mu\mu$ according to Zsigmondy i.e. the specific surface varies from $6\cdot10^{5}$ to $6\cdot10^{7}$, while the ultramicroscope only shows them up or down to 6$\mu\mu$ Mathews gives the colloidal size as 1 to 100$\mu\mu$.

The next consideration is regarding the composition of the particles of the D.P. of the blood serum. The general opinion

is that the D.P.is liquid. "The state in which the D.P.is liquid is known as the emulsoid state"(Hatschek). The reason for this being so is that the only explanation for the observed phenomena of these emulsoids lies in an assumption that the D.P.is liquid. The high viscosity suggests this. Small solid particles can only raise the viscosity by small amounts proportional to the volume of solid matter present e.g.Collosol silver(see P 9)while agar,which is an emulsoid,and is apparently a solid,raises the viscosity some hundred times.(Hatschek) Again,the viscosity alters with the velocity of shear,which supports this view. The importance of this is very great,for we have a system made up as it were of a D.M. and D.P.of similar chemical constitution,but the D.P.contains the substances in a more highly concentrated form.(Hatschek) The result is that it is possible to have a very high concentration possessing liquid form and the range of variation is accordingly much greater. This can be seen when one remembers that droplets can be more easily deformed and can fit in between other droplets in a way solids cannot do. At a very high concentration a solid D.P. would give a paste. Other properties of this emulsoid state which must depend on the D.P.being liquid will be discussed later.

Again the blood serum corresponds to this finding in so far as it has been investigated. My experiments which have taken the form of an investigation of the viscosity of the blood serum support this view,as will be seen later.

We will therefore assume that the blood serum,as it is mostly protein composition,acts like other proteins that have been more fully investigated,and we can therefore take it to be an emulsoid of the composition Liquid+Liquid. The properties which are dependent on this fact require to be considered,so we shall turn in detail to the action of emulsoids and the forces involved.

"Emulsoids are viscous gelatinizing colloidal mixtures not easily coagulable by salts."(Noyes) They have a lower surface tension than the pure D.M. Having a liquid+liquid composition, one may find variation in one or other of the phases, while the remaining phase remains in its previous state. For example, the D.P. at certain temperatures and concentrations may set while the D.M. remains liquid. In very high extremes of concentration the whole may assume constancy of form and elasticity. The particles are very swollen in emulsoids and are united to a great number of liquid molecules. The total concentration affects the system as a whole and influences its state. The D.P. may at one time be semi-solid and then pass to more liquid state and back again. In other words, the system is a complex dispersoid one, and the result of this is that the changes in state are much smoother with changes in Temperature or Concentration than in the case of simple systems. There is also a very thin line of demarcation between the suspensoid and emulsoid state on occasion e.g. Vitellin which is an emulsoid is precipitated by ·1 to ·3% NaCl. The process of formation of the system liquid +liquid in view of these facts of variations of D.P. and D.M. simply becomes, according to Hatschek, an extension of the process of swelling by imbibition with disintegration. That this is probably the case will be seen on considering the surfaces and forces connected with their presence in such a system.

As we have seen, the fundamental property of a dispersoid system is the developement of much surface, and the surface energies which come into play are therefore of great importance. In considering these energies I am largely quoting the views of Ostwald, with especial reference to what he terms surface energy of the second order, but many of the facts quoted are common to all text books of Natural Philosophy, and thus in a sense axiomatic. What is known as surface energy is made up of two factors, a capacity factor measured by

absolute surface and an intensity factor as measured by the surface tension. If this surface energy is freed it is changed into another form of energy,say heat,the surface decreasing simultaneously. If heat is introduced into a system which can develope free surface energy,surface tension is decreased more or less proportionally to the increase in temperature. Supposing that two phases are brought into contact with each other,and they carry opposite electric charges which are not permitted to neutralise each other,the surface tension decreases. Again,the value of surface tension varies also as the chemical character of the phases in contact.

If we turn to gases we see another form of surface energy which is transformed into other forms of energy when the volume increases,in addition to the former kind. The intensity factor of this is called internal pressure. Ostwald holds very strongly that this surface energy of the second order is present in dispersoid systems with an intensity factor of expansive surface tension or negative surface tension. He points to the electric heart of Lehmann where there is a definite increase in the surface of the material surrounding the electrode,and when current is increased the surrounding material even breaks into drops. This expansive energy will again be referred to when we consider the electrical conduct of the particles. An increase in surface of the same condition has been found when solid phases (e.g.Iodine) are brought into contact with liquid without any electric energy(Amann). Kossonagow found electrification increased the effect. This can be observed ultramicroscopically. In complex dispersoids such changes are complicated by changes in concentration and secondary chemical effects.

Now these surface energies are dependent on the specific surface. Thin or markedly curved layers possess relatively greater absolute surface than thicker or less curved ones of equivalent volume. Therefore when more absolute surface is developed,or the specific

surface is increased, there is an increase in Surface Energy. Thus a given volume of D.P. considered absolutely, contains more surface energy than the same volume in a non-disperse state. There is also a relative increase in the surface energy of a single particle. Thus the alteration of the relations of the different kinds of energy in a system into surface energies must have a profound effect upon the character of the system. A very good example of what happens is shown by Ostwald.

Given I = Total energy of a system minus surface energy.
i.e. internal energy.

S = Surface energy

Then Total energy(T) = I + S

The Internal energy is proportional to the volume(V)

The Surface energy is proportional to the surface(S)

I = iv and S = ts (i = internal energy of unit of volume and t its surface tension)

T = iv + ts. Now taking the Total energy of unit of vol $\frac{T}{V} = T_v$ then $T_v = i + (\frac{St}{V})$ if we divide by v. If $\frac{S}{V}$ is small, then the second number is also small, but if v is constant and s is increased it grows in value. If we have great subdivision, i, which is proportional to volume, may practically be neglected in relation to $\frac{st}{V}$. Thus, states Ostawld, all activities then depend on the properties of the surface energy. This condition is more and more the case as we approach the molecular dispersoid state. We can therefore see that before formulating any ideas on the activities of emulsoids we must consider the surface of the particles, and their relationships in the D.M.

When surfaces are markedly curved, they are surrounded by liquid films of special properties, such as great tenacity. It is known that there is a greater concentration of a substance composing a drop at the surface of that drop. The effects of the surface energies extend to a certain depth on both sides of the mathematical surfaces of contact. In a surface which is convexly curved with

regard to one of the phases,and which has a positive surface tension, the subsurface effects may strengthen each other in the convex phase, while they weaken each other in the concave phase. These weakenings and strengthenings must have reciprocal effects on the surface tensions especially. If they do not neutralise each other,the same surface may assume different values depending on the curvature. When the curvature is so great or the particles are so small or the layers so thin,that the phases come very close to each other or are in actual contact,then there is a marked change in the surface tension. Reynold and Rucker have demonstrated this in soap films.

As soon as the progressive deformation associated with an increase in the surface has attained a certain value the surface becomes discontinuous and dispersion begins. This is also seen under the influence of electrical action. This dispersion is more easy, the greater the surface tension(positive) of the D.P.as compared with the medium.

When the phenomenon of dispersion takes place,there is a rearrangement of the resultant particles with phenomena arising from their movement. Ostwald suggests that when the surface energy of the expansive type is in excess,and the usual surface energy of the first order prevents an increase in surface,then the energy reacts upon the D.M. and transforms its tension into pressure acting on its surface layer. There are certainly special properties at the boundaries of a liquid surrounding another phase.

When certain increases in surface are brought about in dispersion,the increase in the contractile surface energy is greater than the decrease in expansile surface energy,for this contractile surface energy results in a discontinuity of the surface. Thus there is in dispersion a liberation of surface energy produced by an excessive developement of absolute surface,through the effects of the expansile surface energy. Then the greater the contractile energy,

the greater is the dispersion.

A diminution in the total surface may be got by the coalescence of particles,or even to a slight degree when elongated particles become spherical. This is seen when the system is cooled, because the positive surface tension between two phases always increases with decrease in Temperature. Condensations are produced by the same interaction of energies,only different concentrations etc have to be used e.g. electric energy has a dispersoid effect,while removal of the charge leads to condensation. With certain changes, on the other hand they may be caused electrically as in the coalescence of electrified droplets.(Rayleigh Proc.Roy.Soc.London 1879-1882). This fact will be referred to later on in the discussion of my electrical experiments viewed ultramicroscopically.

Sudden mechanical pressure one sided,may also cause condensation. There is an intimate contact of the particles required. The particles may not appear to be so,but their liquid membranes are. Against such contact is the fact that there is surrounding the D.P. or rather in its surface a denser state similar to the vapour envelopes surrounding drops when water is poured on a hot surface. Further,for contact there must be a movement of the particles towards each other. Once there is an aggregation there comes to be a common surface film. This becomes smaller and the surface energy (contractile)tends to approximate the particles more nearly. The process ceases when the contractile energy is equal to the expansile energy. The surface energies are greatly influenced by the Temperature and pressure e.g. Given the Temperature,the vapour pressure of droplets is greater than the vapour pressure of water in large masses. In a closed system the smaller droplets condense on the larger ones. Pawlow found that salol dust melts at a temperature 7 degrees less than that required to melt larger particles,and he calculated that a difference in respect of 2·8° was equal to a hundred times increase in Specific surface.

There is also a relation between surface energies and electrical energy which will be discussed later.

As chemical changes, according to Menzel, are proportional in unit time to the absolute surface, colloidal systems show markedly rapid chemical change, e.g. colloidal sulphur is an energetic reducing agent to silver salts. If the phases have different surface concentrations in space there are very great surface effects, and the systems have marked catalytic effects. Organic ferments can be closely imitated by colloid metals.(Bredig)

When we realise the meaning of the foregoing summary of emulsoids in general, we see that the blood serum as an emulsoid contains the same possibilities of great variation, of constant change, and of smooth action depending on the action and reaction of these two surface energies, contractile and expansile. We are again driven to the conclusion that the phenomena which may take place are due to the presence of these minute particles in the serum. It has of course been impossible to test all these views which come from various sources, but in so far as surface changes are concerned, that they occur and can be observed under various conditions will be shown later. One defers the description of one's observations until one has given a further description of other phenomena connected with these particles.

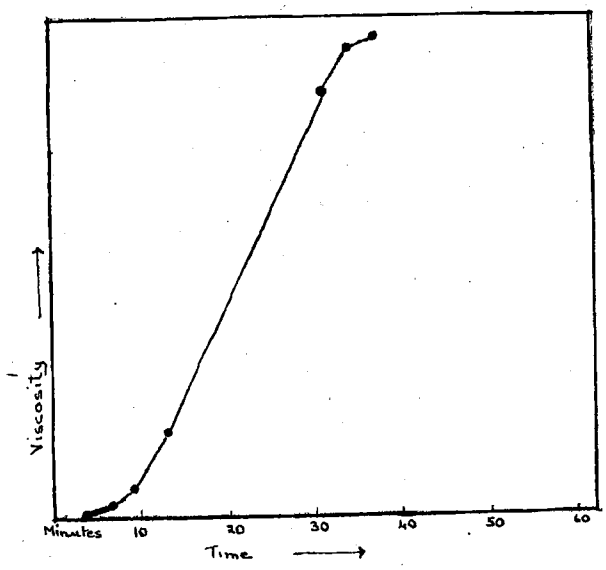
If a chemical reaction occurs in the zone of contact between two phases in which positive Surface Tension is present, the Surface Tension may be raised or lowered. If it is raised the chemical resistance will be decreased through the consumption of energy necessary to raise the surface tension, but if it is lowered, acceleration will occur, for the lowering of it will free energy which will be transformed into chemical energy. Thus a great specific surface will influence and possibly alter the equilibrium point of a chemical reaction.

Thus we see that the particles have a great influence on chemical reactions. Of course the chemical reaction is even more greatly influenced by the molecular state where the practically the whole system is surface, but here again we see that the colloid subdivision results in a smoother action than either of the other forms of solution.

Again, we see that the dispersion of substance makes it more sensitive to radiant energy. This is seen in the making of photographic plates. Stas has shown that the degree of dispersion influences the photo-chemical sensitiveness of silver chloride precipitate. Also when radio-active substances are dispersed the emanations are much increased e.g. in Thorium sol the radio-activity of the sol was 48 times as great as that of the coarsely dispersed element. (Wedekind and Baumhauer) This raises interesting speculations in one's mind as to how, for example, sunlight and other rays have such a peculiar value in the healing of wounds, treatment of skin conditions etc. I found the Pointolite to have an excellent stimulating effect on slow unhealthy granulations.

Further, the density of the D.P. and the D.M. in a liquid + liquid system differ e.g. drops of water 3μ in diameter are ·00005 denser than water en masse. This is small, but if the drops are colloidal size, say ·03μ then D is equal to ·5% greater than water. In emulsoids this change has been noted. e.g. Dried egg albumin-water (100 gms albumin 163·9cc water) showed quite an appreciable decrease in volume viz. 4·175cc in 36 hours. (Ostwald) This bears out Hatschek in his description of the liquid + liquid system as being a system with the D.P. highly concentrated in a D.M. of practically the same constitution. (see above)

In addition, we find the freezing point, the boiling point and the Vapour Pressure depend on the degree of dispersion. The alteration in the degree of dispersion will create a great



Increase in viscosity of emulsoids with time. (Bilty, Schroeder, Levites)

Fig. I.

Gelatine Solutions (P von Schroeder)[1]

Time After	Viscosity 21^0	24.8^0	31^0
5 min.	1·83	1·65	1·41
10 "	2·10	1·69	1·41
15 "	2·45	1·74	1·42
30 "	4·13	1·80	1·42
60 "	13·76	1·90	1·42

Table 1.

With blood serum I found the following:-

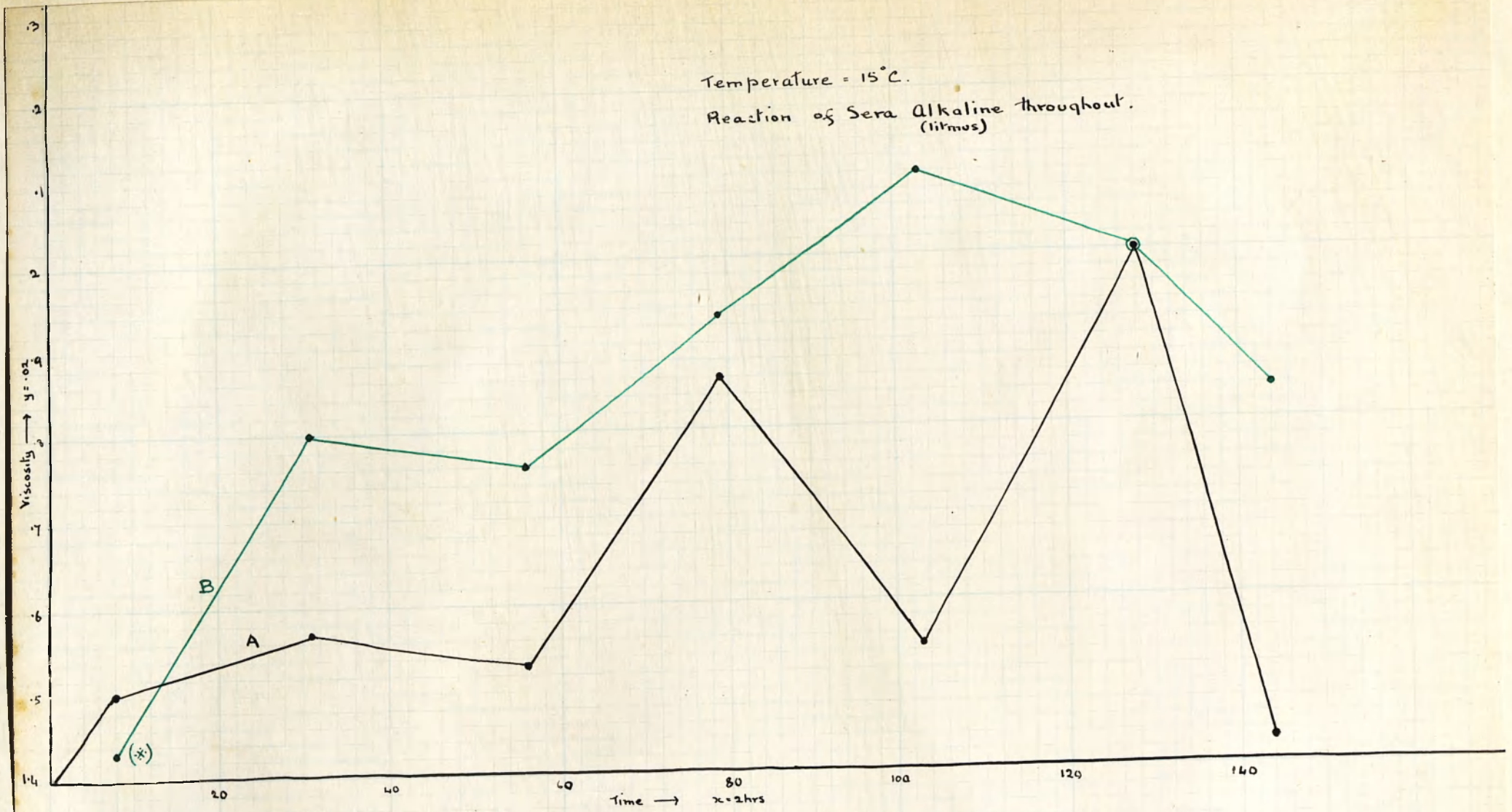
Viscosity of Blood Serum (Alkaline to Litmus)

Temperature 15^0 C.	Viscosity
At start	1·7
After	
20 min.	1·85
25 "	1·7
30 "	1·78
60 "	1·78
180 "	1·78
185 "	1·85

(Appendix A.)

Table 2.

As the first table shows (P. von Schroeder) there is a gradual increase of viscosity with time. This increase of viscosity is sometimes hastened by the addition of a trace of electrolytes, as has been shown by Gokun with Ammonium Nitrate on Gelatine Solutions[1]. Biltz and A. von Vegesack[1] show clear results of the increase with time of Benzo-purpurin solutions, as will be seen in Fig(1). My results found with blood serum closely follow$



※ this low reading due to mechanical lowering of Viscosity (see appendix A)

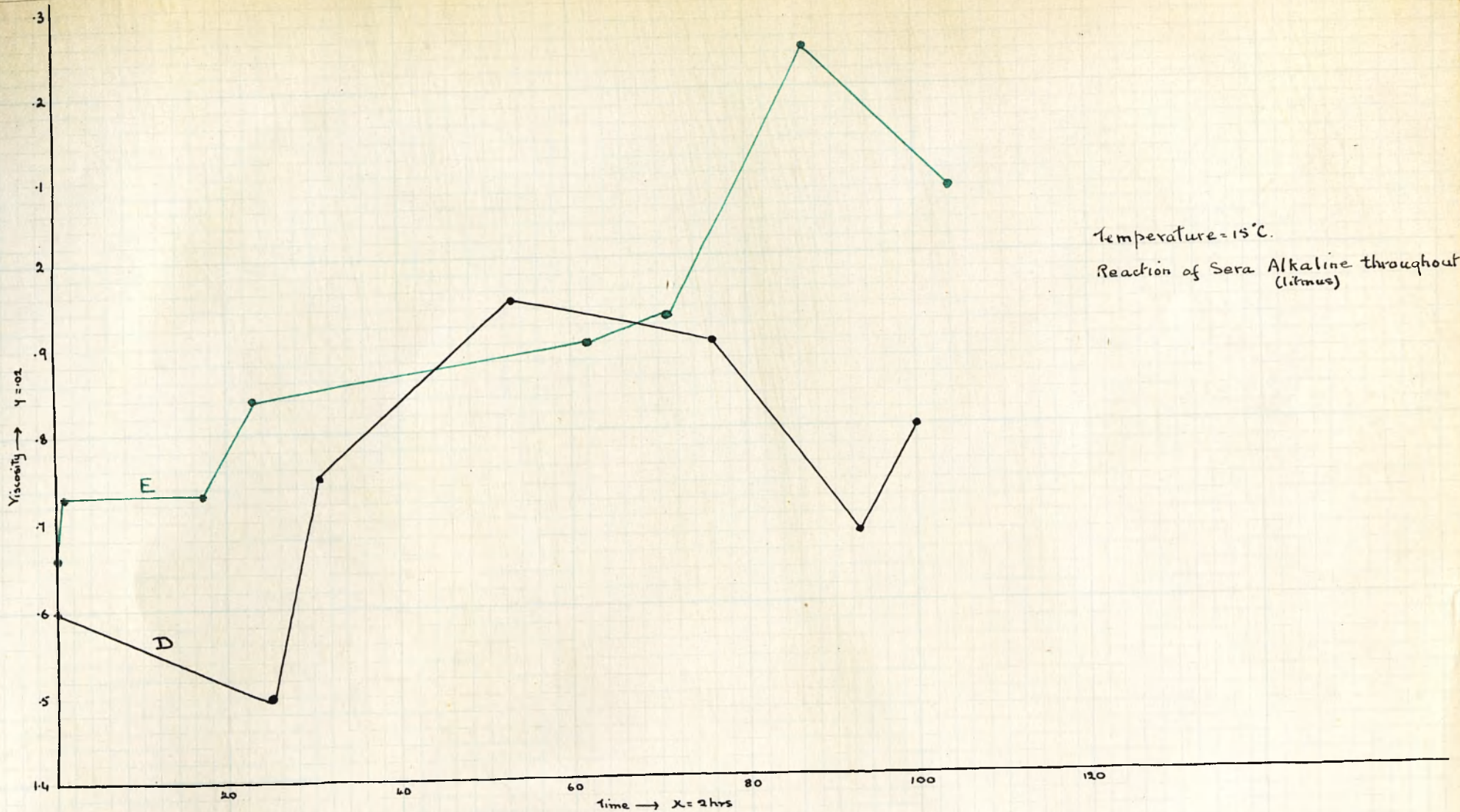
Curve A = { fresh Serum without Inoculation

Curve B = { fresh Serum same as in A with Inoculation

Increase of viscosity of Normal Blood Serum (fresh at Start) with (i) time and (ii) time and "Inoculation" with aged Serum from same person.

Serum for Inoculation 10 days old.

Fig 2a.



Temperature = 15°C.

Reaction of Sera Alkaline throughout (litmus)

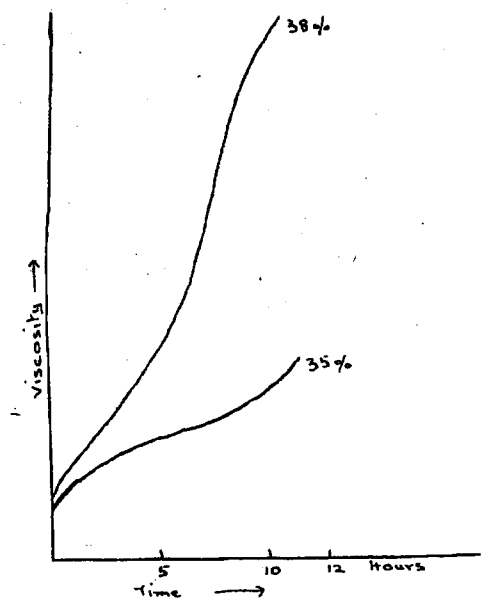
Curve D = {Fresh Serum without Inoculation

Curve E = {Fresh Serum same as in D with Inoculation.

Increase of Viscosity of Normal Blood Serum (fresh at start) with (i) Time and (ii) Time and "Inoculation" with aged Serum from same person

Serum for Inoculation 6 days old.

Fig. 26



Effect of time on the viscosity of serum albumin to which alcohol has been added.
(According to J Simon)

Fig. 3.

their curve(see figs2a &b) There is an initial slight decrease in some instances at first in the case of blood serum(fig 2b) and thereafter the graph shows the rise followed later by a fall. Alcohol has also an effect in causing a more rapid increase in viscosity of serum albumin which result increased with the increase of concentration of alcohol. (see fig 3)(Simon) The ordinary increase due to mixing alcohol with water must be remembered here. My experiment for testing this with blood serum is shown later(P.27.Fig9 Again,mechanical treatment may decrease the viscosity.(Biltz)

Influence of shaking on the viscosity of a 2·7% solution of night blue. (Biltz and Steiner)

Without shaking.	After shaking.
151·5	118·2
143·4	118·0
139·9	118·4

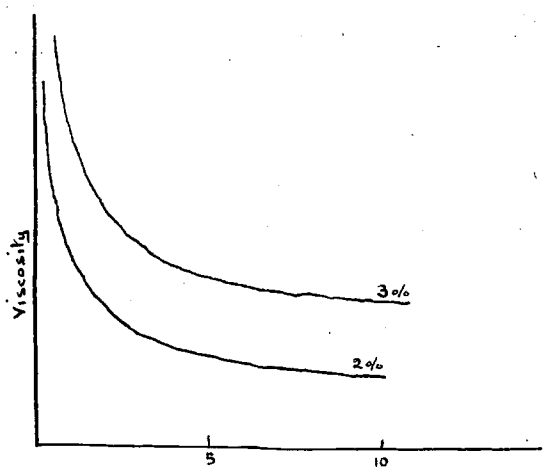
Table 3.

Ostwald states that merely pressing the substance through a viscometer several times will decrease the viscosity. with blood serum I found a slight difference. My results showed practically no greater variation than was found on testing another specimen of serum for variations over short periods of time.

There was a very slight reduction,however,taking the results in this case,compared with a gradual increase in the other.(Page 23) My results were:-

Before shaking V.	After shaking and passing through viscometer continuously,taking readings frequently. V
1·52	1·52
	1·52
	1·43
	1·48
	1·48
	1·43
	1·43

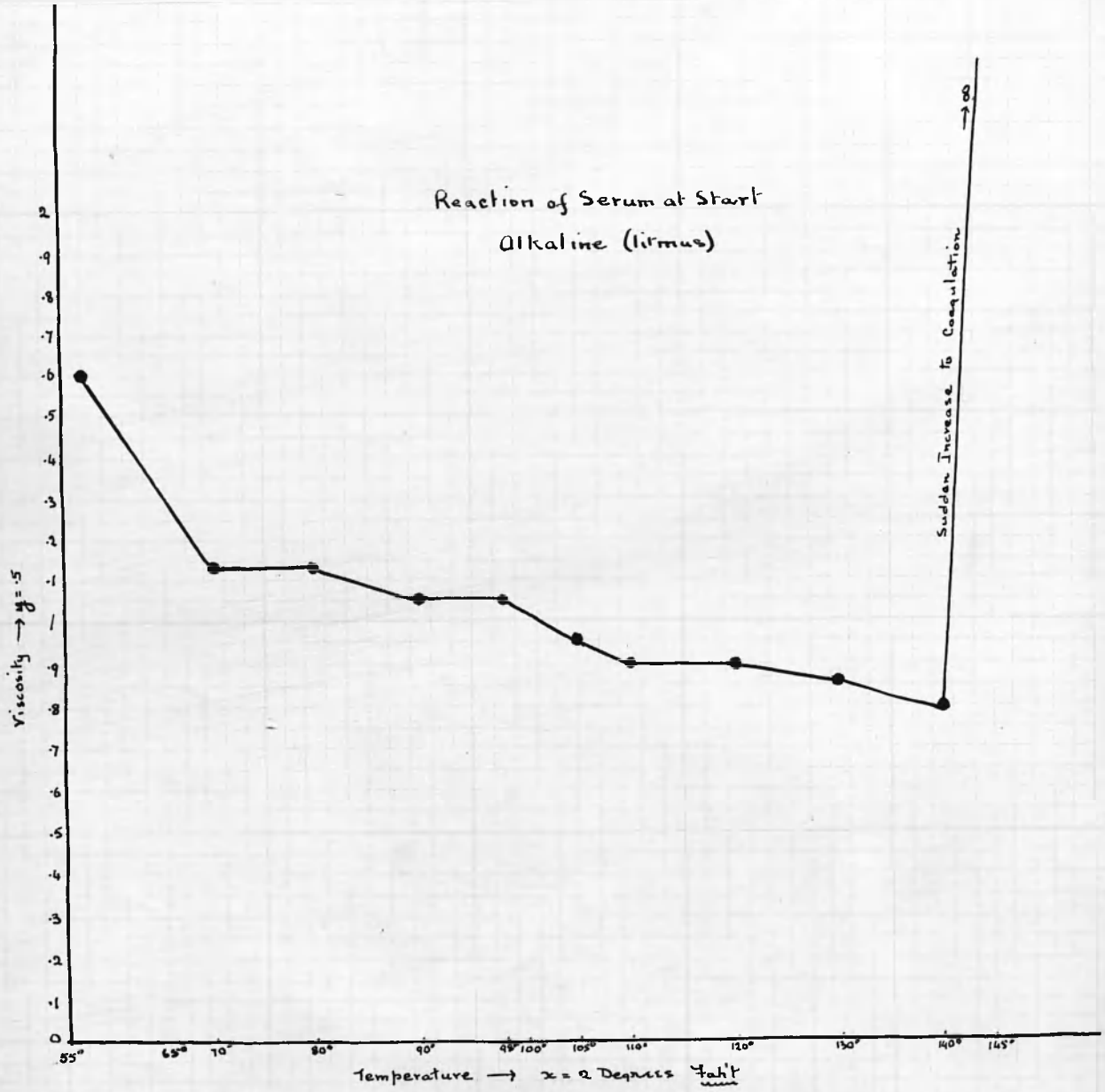
Table 4.



Effect of prolonged heating on the viscosity of a gelatine solution
(According to Schroeder)

Fig. 4.

Note:- The temperature is not shown.



Influence of Heat on Viscosity
of Fresh Normal Blood Serum

Fig. 5

Slides taken at 1·52 and 1·43 did not show any noticable difference in size of particles or in number.

This last fact is of great importance in testing for viscosity and must be remembered in relation to such an experiment. (See appendix A) The next interesting result is got from the inoculation of a system by an older system. This has been done with technical night blue by Biltz and Steiner.

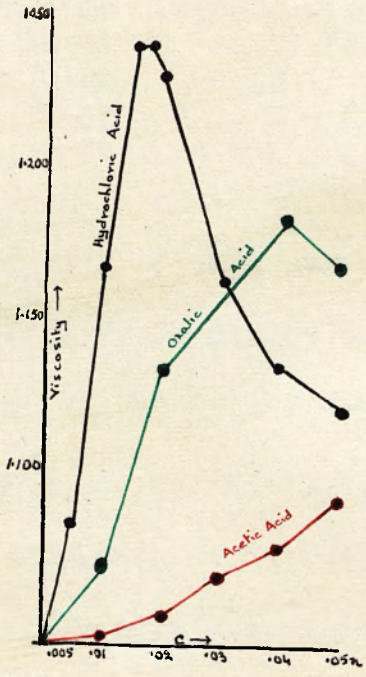
Time of outflow.

Without inoculation				With inoculation			
Per cent.	At once.	1 day.	6 days.	At once.	1 hour.	2 hours.	1 day.
·90	77·2"	78·5"	78·5"	79·2"	-	-	78·8
1·35	79·3	82	81·6	82·2	-	-	82
1·80	77·6	85·6	- -	83·2	86·1	85·6	85·9
2·25	85·2	91·3	102·6	88·9	91·6	103·3	- -

Table 5.

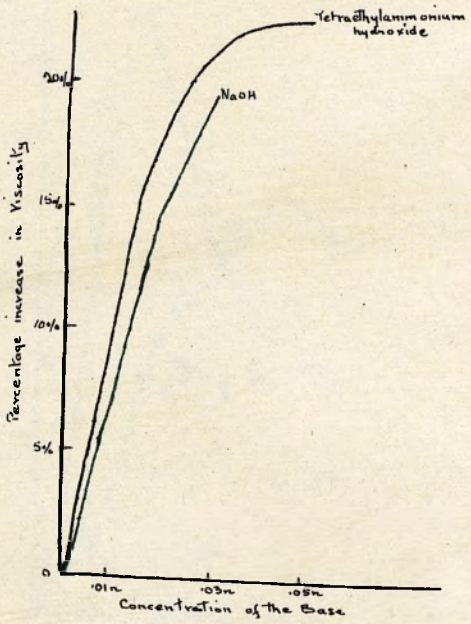
That this was the case to a limited extent with blood serum I also found. The result of inoculation with the same person's serum more aged is seen in figs 2a and 2b compared with the normal rise with time. The effect in the one case seems to be more a steadier rise than a more rapid rise,with also a greater point of viscosity reached. Inoculation with a still older serum gave a much more typical effect. (fig 2a) The behaviour of the particles in this inoculated solution was very instructive,and will be referred to later. On the other hand,a decrease in viscosity,which may,as we have seen,be got by mechanical treatment,can also be got by increase of temperature. This has been shown in the case of gelatine and agar by P.von Schroeder.(see fig 4) Fig 5 will show my results with serum.

The last respect in which viscosity can be altered as far as concerns this paper is by the addition of neutral salts,acids, and alkalis. In this question there is some difference in the findings in regard to emulsoids,owing to the difficulty of



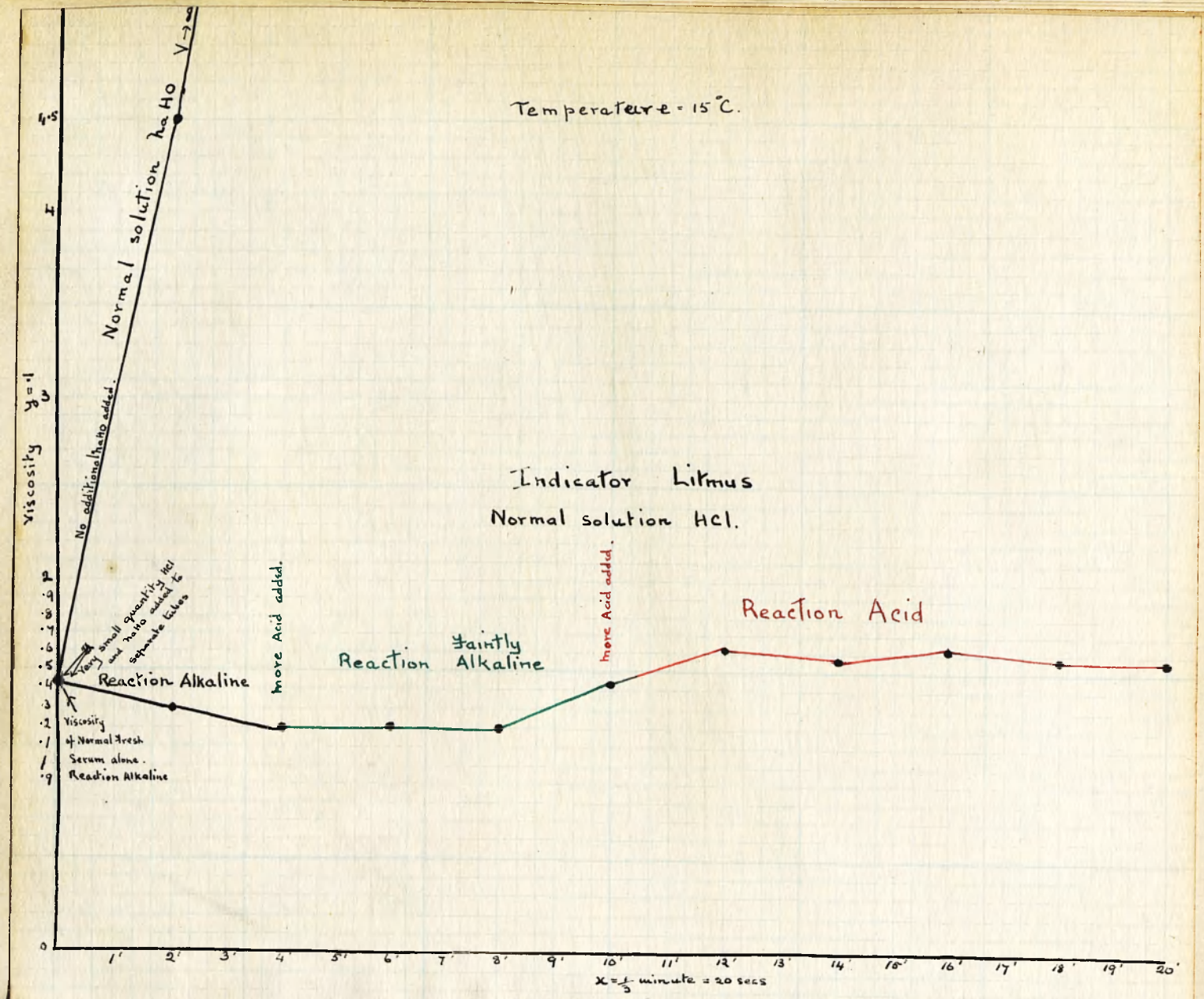
Effect of Acids on the Viscosity of Serum Albumin (Pauli and Handowsky)

Fig 6.



Influence of Bases on the Viscosity of serum albumin.
(Pauli and Handovsky)

Fig 7.



Effect of Acid and Alkali on Normal Blood Serum (fresh) with Time

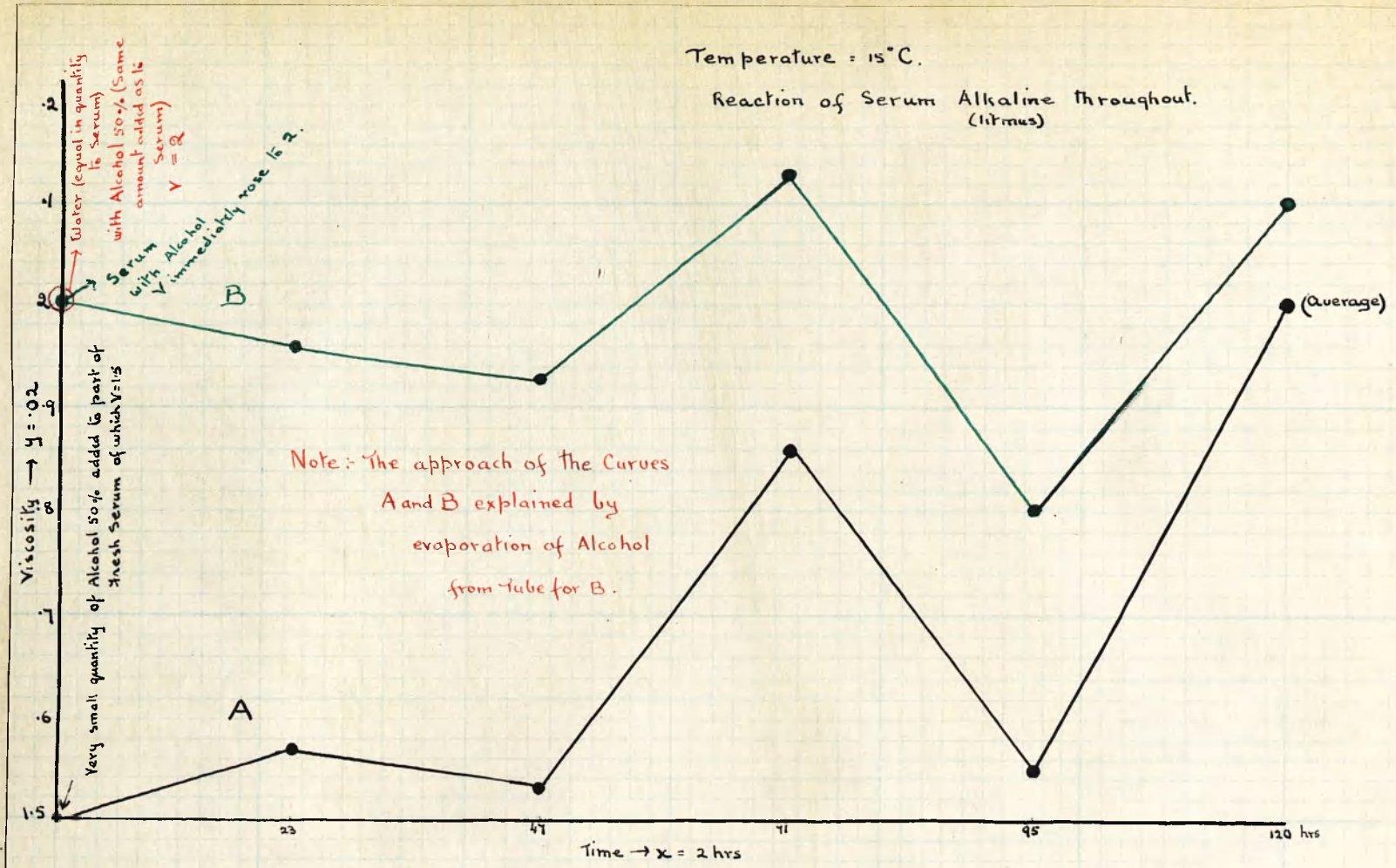
Fig 8.

getting pure preparations. Wo.Pauli,according to Ostwald,has brought out the fact that minute traces of electrolytes markedly affect the viscosity. Here there is a difficulty in that the emulsoid to be tested itself shows varying viscosity. The results for example with gelatine vary greatly,but there have been extensive investigations by various authors on proteins,which are fairly clear and are therefore of value to this paper.

Enormous changes take place with traces of electrolytes. The final viscosity is reached in a remarkably short time. These changes are best shown by reproducing the experiments of Pauli and Handowsky. (see figs 6 and 7)

I have only been able up to date to test the effect of a Normal solution of HCl and NaHO The results (Fig 8) confirm these findings,but the result with NaHO goes further. The slides taken confirm my description of other slides taken on increase of viscosity with time and inoculation. The slides taken during these reactions gave the following notes:-

At start before adding Acid or Alkali:- 1·43 Reaction Alkaline.	Particles medium to large medium,with some small-a fair number conglomerates-small. Fairly numerous. Electro-negative.
At 12 min. with Acid 1·62 Reaction Acid.	Particles generally medium-some more large- more conglomerates,general number about the same. Still Electro-negative.
At 2 min. with Alkali.	Small,medium and large particles,about the same number. Tremendous increase in conglomerates. Some precipitated masses. Very slow Brownian Movement.
At 4 min With Alkali.	Slide same,but Brownian Movement ceased.



Curve A = Serum alone

Curve B = Serum and Alcohol

Effect of Alcohol 50% on Viscosity of Normal Blood Serum (Fresh at start) with time with Control at start of Alcohol and water.

Fig. 9

Where salts are concerned the effect varies according to the reaction of the system e.g. whether acid,alkaline,or neutral albumin is used. Neutral protein has its viscosity lowered by neutral salts. (Pauli) In acid albumin the anions of neutral salts have more influence than the cations. The reverse is found with alkaline albumin where the cations play the greater part. The result is a decrease in viscosity.

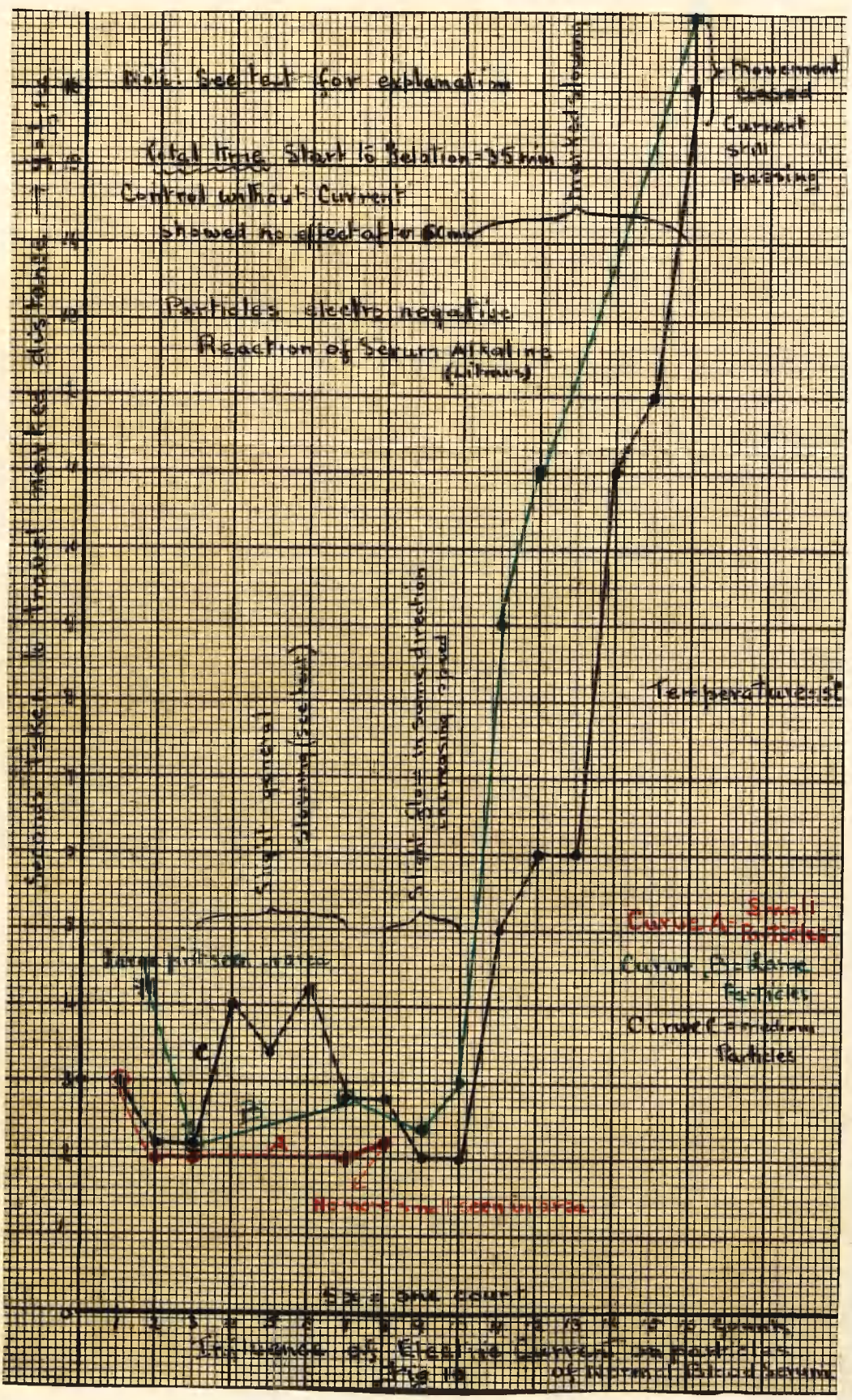
With regard to non-electrolytes we have already mentioned the effect of alcohol,but will presently give my results.

Handowsky found that caffeine increased the viscosity of acid albumin. On the other hand Pauli and others declare that the result of the addition of non-electrolytes is only due to the increase in viscosity of the pure D.M. My experiments with alcohol and serum will show that a control will clear up this point,as Ostwald suggested.(see fig 9) The result confirms Pauli.

The cause of viscosity now falls to be considered. Viscosity is of course simply internal friction,and is a question of the ease of movement of the individual molecules,ions,or larger bodies in a fluid. Now if there is any attraction between these bodies in the fluid,or if they are of such a size as to obstruct each other when in a limited space it is obvious that the viscosity will be increased. Not only does the question of size of the individual bodies enter into the question,but the amount of separation between them also comes into account. For example,if,in a piece of copper,on a current passing,the atoms or molecules were the only bodies that moved, and they moved towards the pole opposite in sign to their charge, it is quite clear that the internal friction would be enormous owing to the closeness of the atoms to each other. This is an extreme instance,for in copper this movement is almost nil,and the actual movement is that of the electrons which are so minute that they have

relatively greater ease of movement and space in which to move. The viscosity therefore is infinitely great while the copper is in solid form, because viscosity is concerned not with the electrons so much as with the larger ions. In a fluid on a current passing, there is of course an electron current but there is also the passage of the comparitively greater ions or "charged atoms" towards the respective poles. One would therefore judge that the smaller the charged bodies i.e. the greater the dissociation, the less would be the viscosity. Other factors, however due to the charged condition of the atoms come into play." There is an electro-magnetic field about each "charged atom" which hinders its movement." (Ostwald). At this point one must again consider the views of others especially as they do not at first seem to correspond with my own experience.

We see that this field about a charged atom or ion hinders its movement. The deduction made by many is therefore that as only the ions are the charged bodies, it must follow that the greater the dissociation the more of these ions exist, and therefore the greater the dissociation, the greater the viscosity, because the more atoms have thus a hindering electro-magnetic field. Ostwald states that the viscosity is due to an increase in the number of particles in colloidal solutions, and the greater the increase in dissociation of the D.P. the greater the viscosity. If this is the case, then taking his view of the D.P. as a separate substance i.e. constant total volume, the dissociation can only result in a lessening of the size of the particles to allow an increase in their number. That there may be a dissociation, or rather, an increase in number of particles, there is no doubt, but I have found in addition that there is an increase in the size of many of the particles with an increase in viscosity. Not only do the individual particles increase in size but they appear to occur in conglomerate masses. This coincides with an increase in viscosity.


Note: See text for explanation
Total time Start to Relation = 35 min
Control without Current showed no effect after 60 min
Particles electro negative
Reaction of Serum Alkaline (Litmus)
Movement ceased
Current still passing
Temperature: 5°
Curve A: Small particles
Curve B: Large particles
Curve C: Medium particles
Large particles entire
Slight deposit (Sediment)
Slight deposit in one direction
Remainder remained in suspension
Size one count
Influence of Electric Current on particles of Serum Bacillus Anthracis

In fig 10 I have attempted to show graphically the general increase in the size of the particles on the passage of an electric current,while the viscosity increased so greatly that finally a stage of no movement at all was reached. The graph is really not a very accurate one in its (X) abscissa,but is merely a representation of a number of counts of particles as seen in an area of an electric field with the ultramicroscope. Details are given in Appendix B, of the experiment . The aim was to show how size affected speed and this is also demonstrated in fig 10. The counts could not be taken at exact intervals owing to different times for focussing and for getting the particles on to the area covered by the micrometer scale The vertical (Y) line is marked in secs and the time is graphed for the particle to travel a given distance under the influence of an electric field towards,in this case,the positive pole. The X abscissa the longitudinal one,merely gives the number of counts. Each count was if possible,one in which the speed of a small,medium and large particle was taken at the same focus. Where this is not shown the cause is the absence of a particle of the type required in the given area. The three curves indicate the speed of large,medium and small particles respectively. It will be noticed that as the count proceeded the number of large particles increased,while the small ones were not to be seen. Actually at the start of the experiment the particles were almost entirely medium size,but about 15 secs after switching on the current the small particles were seen. A possible explanation of this will be given later. At the end of the experiment(35 mins) all movement had ceased and apparently gelation had set in.

The stopping of the movement was quite gradual and not sudden. The only possible causes of this were(1) too great heat reflected from the lamp,(2) heat caused by the current,(3) action of the current. This was checked by a control,and (3) was shown to be the only possible cause. The heat of the lamp was much greater than any created by the current,and even reflected lamp heat had no effect on a control after 60 mins. The heat radiations from the lamp apart from reflected heat had no effect on the control slide either.
We have therefore the definite result that the passage of an electric current increases the general size of the particles and finally increases the viscosity to the point of coagulation.
As seen further from fig 10 the speed of the larger particles was on the whole slower than the medium and smaller ones,except near the start of the experiment when there was a temporary marked slowing of the medium particles at a time when few large ones were seen. This temporary slowing was due I think to a flow in the opposite direction from streaming movements which also reversed and gave a sudden speeding up of the large and medium particles.

As, however,it was felt that other causes might be present which would lead to gelation,the experiment was repeated macroscopically with slides taken at intervals which were examined ultramicroscopically. Details are given in Appendix C. It was then found that complete gelation was produced in a small quantity of serum by the electrolytic action of 1 Volt E.M.F.
The ultramicroscopic appearance was noted at intervals.
To avoid the personal equation,I requested the opinion of a fellow Officer who was neither in the medical branch nor experienced in microscopy. He was asked to describe the slides without knowing what results were expected. His opinion corresponded exactly with my notes without any leading questions being put to him. These are now given as they were written down by me previous to his less technical

description which confirmed them.

Appearance of slides from electro-lysed serum. Taken while current in action.

At start 11 pm	Particles small-fairly dispersed not very numerous a few small conglomerates. Brownian movement active.
At 11-20	Particles small and medium-about same as to numbers. Brownian movement.
At 12 pm	Particles (medium) more numerous-total number same. Conglomerates still small. Brownian movement.
At 1 am	Particles medium about same size-if anything some larger and these more numerous. General numbers about the same. Brownian movement.
At 12 noon	In tube substance extremely viscous and sticky inside tube,(see Appendix C) removed after moistening with water in a "blob"from U.(my own note only) Slide shows mainly large medium,large,and small also. Very faint slow Brownian movement.(Officer thought no movement at all) Many conglomerates.

This experiment entirely confirmed my previous findings. It is to be noted that this coalescence under electrical action differs from Ostwald's previous statements,referred to on p. 16,19 but coincides with the findings of Raleigh.(see p. 19)

Ostwald points out,as is well known,that ions are also hydrated i.e.have water "envelopes", and he therefore deduces that in the increased dissociation there will be more water envelopes to be dragged along by more particles,and thus with more numerous particles although smaller the viscosity is increased.

If however my experiments are correct and there is an increase in the size of the particles,and yet an increase in dissociation,there must be an additional factor. I venture to suggest that the increase in smaller particles which I only saw at first with an electric current and not later,and which I have not always been able to confirm in slides of sera of which the viscosity has increased from other causes,is due to dissociation of the D.M. with an increase in size of the hydrated ions to micronic size i.e.

particles below 10^{-7} cm. to within ultramicroscopic range. This view is possible if the system is liquid + liquid, the difference being one mainly of concentration, as Hatschek suggested. The question of the surface forces coming into play here will be discussed later. The greater concentration is accompanied by a lesser degree of dispersion as far as the original visible D.P. is concerned (see p. 12) but the increased number of smaller particles also appears to be present here for the reasons mentioned. The change in concentration is the important factor, as will be discussed later.

I cannot find in the literature any record of comparisons at the same moment between viscosity and actual ultramicroscopic appearance, and therefore venture to adhere to the view that an increase in size goes with viscosity increase, and the above seems to be the only explanation to fit in with Ostwald's statements and my findings. It might be that the apparently larger particles are conglomerates of a minute size, but their appearance does not suggest this. I, further, am of opinion that the presence of hydration in relation to ions can hold here too, as will be seen later when I discuss the manner of the increase or decrease in size of the particles. We at least see that viscosity is intimately connected with the particles present in the D.M. and that varying forces come into play due to the presence of great specific surface, and that under various outside agencies this viscosity is changed.

The relation of the change of particles to the viscosity through other forces than the electric force will be mentioned later. As the electron theory has unquestionally shown, these other forces, such as heat and cold, are merely manifestations of electric force in another form, but they are referred to as if different for the sake of avoiding a detailed description of the electronic explanation of heat etc.

Heat, further has been found to decrease viscosity. This will be shown by Fig 5. The behaviour of the particles in this case is doubtful, and the results and their comparison to electrical findings are discussed in the later more theoretical portions of this paper.

With regard to my ultramicroscopic findings along with viscosity tests, and the opinion of others in relation to Degree of Dispersion, opposing views are held. For example, Beck and Ebbinghaus found that increasing the dispersion of a coarse emulsion of castor oil in water increased the viscosity. On the other hand, increase of molecular weight is known to increase viscosity (Ostwald) The final result may be that it will be shown that the medium degree of dispersion gives highest viscosity, as Ostwald suggests. My findings under various conditions are now given.

If we take Figs 2a and 4, and examine the results of notes on a few slides coincidently we shall see how far my observations are confirmed. As in the former case when examining slides from serum undergoing electrolysis, I asked the opinion of another Officer and his observations confirmed my notes. Slides were taken at the viscosities noted. They were not taken more frequently as the amount of serum was limited. The following are the notes:-

V	Fresh Serum Fig 2a Curve A	V	Serum with alcohol 50% Fig 4q.
1·5	Medium Particles-very numerous a very few conglomerates.	2	Medium size, a few conglomerates like normal.
1·86	Particles slightly larger-still very numerous-more conglomerates.	2·13	Particles slightly larger-very numerous more conglomerates
2	Particles not quite so numerous more conglomerates slightly bigger.		Also a few masses of precipitate such as
1·43	Particles very numerous and very small very few conglomerates,		in slide of serum precipitated by alcohol (90%).

	Fresh Serum (95 hrs) (fig 2b Curve D)		Same Inoculated (87 hrs) (Fig 2b Curve E)
V		V.	
1·7	Particles much smaller than inoculated slide, more medium size, few conglomerates.	2·21	Particles much larger than original, several conglomerates.

As noted on fig 4 the effect of alcohol on the viscosity seemed to be due to the increase of the viscosity of the water only, and these notes on the slides suggest this also. The question of the Degree of Dispersion must remain unsolved experimentally as far as this paper goes, as the calculation of it comparatively for various sera involves great difficulties ~~at present~~ impossible of solution under my present circumstances. (see Appendix B)

Before proceeding to discuss the variations in the size of the particles one must briefly consider the findings of others regarding their behaviour and influence on other properties of the serum. While the experiments related are the main results of my personal investigations one must complete the evidence for one's view on the importance of the particles in the body reactions before discussing the relation of one's conclusions to practical medicine and one's theories on the basis of abnormalities in the body which lead to symptoms.

We shall therefore consider Brownian Movement with the particular aim of seeing what appears to be the physical value of the particles which play such a great part in alterations of the blood serum. The appearance etc. of this movement we are not concerned with, except in that it obviously is dependent on the state of the D.M. As noted in my description of the ultramicroscopic appearance of the serum under the effect of an electric current, the Brownian movement decreases when the serum reaches more nearly to the state of gelation.

In addition one noted that the increase in size coincides with lessened movement even without the increase in viscosity i.e. in fresh serum the very few larger particles move more slowly than the smaller ones. Another point noted was that the arc light seemed to increase movement, for when the light was partially shaded the movement was less than when the light was not interfered with. Again, as noted by Mathews, I found that heat increased the movement. Possibly the effect of light was due to that, as I had no means of keeping off the heat of the light rays. The heat from the lamp box was kept from the microscope by asbestos but not the heat of the actual lamp. In other words, when the viscosity was less, the movement was greater.

As to the cause of the movement there are varying opinions. Mathews ascribes it to the bombardment of the particles by the molecules of the D.M. That this is more or less generally accepted is the case.

According to Ostwald, every possible factor due to external agencies has been eliminated and the property of Brownian movement is inherent to a disperse system. There is no occasion to go into the experiments which eliminated these external factors.

Svedberg carried out extensive experiments in regard to the matter, and the main findings that concern this paper are that he found the amplitude was directly proportional to the period and inversely proportional to the viscosity of the liquid. The influence of temperature lies in the fact that it changes the viscosity. It is to be noted that this finding might indirectly confirm what I have previously maintained, that there is a relation between the size of the particles and viscosity, because the particles being generally larger in size with increased viscosity also move more slowly. The interest of the experimental findings

of Svedberg lies in the fact that Einstein and Smoluchowski applied their mathematical equations for the Kinetics of Disperse systems and found that the results, reached mathematically, confirmed the experimental results of Svedberg. As this equation, for they both reached practically the same equation except for a constant, will be referred to again it is now given. Particulars as to its derivation can be got elsewhere. (Einstein Ann, d. Physik) (1905) - Smoluchowski Ann. d. Physik (1906).

This formula is :-

$$\Delta = \sqrt{K \cdot \frac{RT}{N} \cdot \frac{t}{\eta r}}$$

Where Δ = average path length K = constant R = Gas constant

T = absolute temperature N = no of particles in a gram-molecule of the D.P. t = period of vibration

η = viscosity of D.M. r = rad. of particle.

As Ostwald points out, if we have given all the factors constant except Δ, t, $\propto \eta$ then $\Delta = K\sqrt{\frac{t}{\eta}}$ Thus the viscosity factor is seen to be of great importance. Svedberg showed, as we saw, that the viscosity is experimentally one of the two great factors in Brownian movement. In other words we see that these findings are strongly in favour of the Moleculo-Kinetic theory.

Again, particles of radius ·14μ to ·45μ have been found by Perrin to conform to what is known as Stokes law, which involves the velocity of small globules under forces acting on them such as gravity viz:- $V = \frac{2}{9} \cdot \frac{D-d}{\eta} K \cdot r^2$, where V = velocity D = density of particle, d = density of liquid, η = viscosity, K = constant of gravity and r = radius of particle. How far this applies to colloidal disperse systems is not yet known, but J. Thomson has applied it with great success to gaseous ions in their migratory phenomena.

While these moleculo-kinetic findings with other experiments have gone to prove very largely that the Brownian

Movement is due to these factors only, Ostwald points out that the study of gaseous ions has shown, as we have already mentioned, that an electrically charged particle induces in its surroundings an electro-magnetic field which retards its movement. Further, he states, that traces of electrolytes absorbed by the particles retard their movement through changing their charges in a positive or negative sense. The fact of the charge of the particles affecting Brownian movement, however, does not take away greatly from the moleculo-kinetic theory, for after all the ionic motion which would cause the bombardment is fundamentally due to electrical action.

Another factor has been described as retarding Brownian movement Viz:-the addition of electrolytes. Svedberg notes that this, however, is due to the electrolytes causing an increase in size of the particles. On the other hand others have found that the movement might be accelerated by electrolytes. In a neutral medium the path length averaged ·62μ per $\frac{1}{20}$ sec, but was reduced in an alkaline to ·31μ and in an acid to ·07μ (Henri).

These findings are, in my opinion, probably the results of the varying electrical condition of the system with consequent change in size of the particles. It would be necessary to know the substances used to formulate a proper opinion. These results, however, take us one step further in our consideration.

We have seen the importance of the particles, the result of their presence in the production of great specific surface, and the presence of great surface energies, their profound relation to viscosity, and their apparent increase in size, generally speaking, with rise of viscosity, and decrease in certain cases with fall in viscosity given other things constant. We have seen that Brownian movement experiments have confirmed my experiments showing that alterations in viscosity affect movement, and that the size of the

particles has an intimate relation to the movement under a force, according to Stokes' law. Further, these findings lead us to the conclusion that in their behaviour the particles follow moleculo-kinetic laws and, as Hatschek points out, they can be treated as molecules of a substance of very high molecular weight. These conclusions will be referred to again, but before proceeding to apply them, one must turn to the remaining phenomena, without a consideration of which the object of this paper would not be attained.

Svedberg for gold sols found that the diffusion velocity was approximately inversely proportional to the size of the particles. Here again the moleculo-kinetic equation of Einstein and Smoluchowski provided mathematical proof. From the equation previously mentioned they developed the diffusion coefficients for the D.P. and found it to be $D = \frac{RT}{N} \cdot \frac{1}{6\pi\eta r}$.

If the factors D and r are constant, then $\frac{D_1}{D_2} = \frac{r_1}{r_2}$ i.e. the diffusion coefficients of two dispersoid phases vary inversely as the respective radii of the particles. Again we see the importance of the size of the particles. If we turn to the remaining properties of the liquid disperse system we find the dialytic and osmotic phenomena again support our contention. When one gets dialysis there is usually present a certain amount of osmosis. The osmosis, as does free diffusion, tends towards the establishment of a uniform spatial distribution of the D.P. and D.M. (Ostwald) For osmosis one requires a membrane, and the phenomenon is really, as it were, another side to dialysis. The osmotic pressure and other phenomena are markedly dependent on the specific surface of the D.P. and colloidal solutions if pure show very small pressures. Electrolytes even in minute quantities affect the system greatly, but the pressure even with these present is very low.

Further, the slightest alteration in the circumstances produces changes in the Osmotic pressure, as shown by Reid.

Influence of previous treatment on Osmotic Pressure of albumin. (E.W.Reid.)

Previous Treatment.	Osmotic pressure of a solution in mm Hg.
Ovalbumin twice crystallised and once washed.	3 · 38
Ovalbumin washed repeatedly.	0 · 00
Ovalbumin precipitated and once washed.	4 · 82
Precipitated bovine serum albumin once washed.	4 · 29

Table 7.

The age of a system varies osmotic pressure, and the alterations are similar to the changes in viscosity from similar circumstances.

Again, colloids do not in the relation of osmotic pressure to concentration follow the Van't Hoff laws for molecular dispersoids viz:- that the O.P. is directly proportional to the concentration. Ostwald refers to cases where the O.P. may increase faster or slower than the concentration.

Relation of Osmotic Pressure of Haemo-globin solutions to their consentrations.

Concentration.	Temperature.	Osmotic pressure in mmHg.
2 92%	15^0	12
4 58	15^0	17
4 95	15^0	19
5 7	15^0	17
6 05	15^0	22

Table 8.

Nor again, does the Osmotic pressure vary proportionally with the absolute temperature in all cases. Also, acids and

alkalies may either increase or decrease the O.P. in different colloids or in even the same one. For example, Bayliss found the O.P. of pure highly dispersed Congo ~~Red~~ Red to fall 87mm when the outer water was saturated with CO_2. Alkalies increase the O.P. to a maximum beyond which it falls again. The acids led to a drop at first and then to an increase. This was in the case of gelatin, but on the other hand egg albumin O.P. is always lessened by both acids or alkalies. The addition of salts always causes a decrease, the degree of which varies with the concentration and with the nature of the anion and cation. As Ostwald points out the results which often seem contradictory depend on the original reaction of the colloid.

I have purposely avoided much detail in the consideration of O.P. because I have not been in a position to test any of the findings for myself, but the above is sufficient to indicate that the O.P. of a colloid shows extremely variable results. This Ostwald suggests is due to the fundamental difference between them and molecular dispersoids, the presence of additional factors introduced by the presence of the larger particles. The most important of these factors is the size of these particles and their degree of dispersion. Bayliss has shown with Congo red that anything which decreases the degree of dispersion decreases the O.P.

As could be further shown Einstein and Smoluchowski have also shown mathematically the influence of the radii of the particles on O.P. Therefore again we find the great importance of the particles in phenomena which, as we know, form two of the great physiological reactions of the cells of the body, osmosis and diffusion.

The logical consequence of a study of the osmotic, dialytic, and diffusion phenomena leads one inevitably to the

consideration of the last property to be considered viz.gelation. While,in the body,the blood serum does not gel except abnormally, yet an increase in viscosity is,as we saw in my electrical experiments,a step towards gelation. As we discuss it we are inevitably brought to the final consideration of this paper,the causes of the alterations of the particles in the blood serum, and from it we can deduce the changes which accompany increase or decrease of viscosity while the system still remains liquid.

A sol becomes a gel when its degree of dispersion is decreased so that the system becomes microscopically heterogeneous.(Ostwald) The sol, in other words,coagulates,or as some say,gelatinizes. This precipitation may be reversible or irreversible i.e. if the cause is removed it returns to its former state. When one turns to the investigation of blood serum one is struck with the occurrence of a peculiar phenomenon. As we have seen,an electric current causes gradual increase in viscosity to the point of gelation. On the other hand heat causes a decrease in viscosity up to a point of sudden "precipitation" of one or more of the proteins involved. Ostwald notes a similar condition in other colloids. He states that the reversibility of such a change of condition is not determined by the nature of the colloid but rather by the character of the conditions which produce the coagulation. For example he states that the precipitation of typical protein sols by neutral salts is reversible but their "precipitation" by heat is irreversible.⁂ In my experiments on the passage of electric currents,the gelation caused by it was slightly reversible in a sense,for on addition of water to the slide the Brownian movement was seen to recommence gradually although there was no change of the whole mass. What seemed to occur was a decrease of concentration of

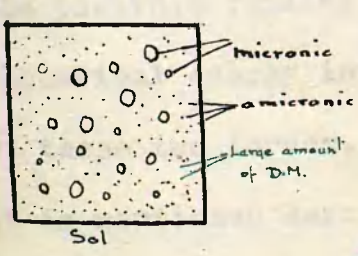
(⁂ See also page 48)

of D.P. at least to a small extent. The effect of the current was clearly due to removal of water by the electrolysis together with the increase in size of the particles. There were the two occurrences happening simultaneously. This will be further discussed when one has considered other views on this subject.

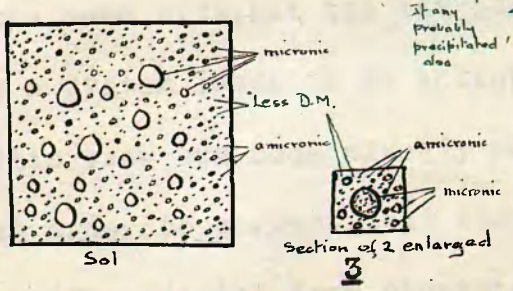
As I have mentioned, Ostwald and others refer to precipitations, coagulations etc, as resulting in gel formation. It is necessary to make a clear distinction however between the gel condition and other forms of precipitation. In the precipitation by salts of a colloid there is a separation of the solvent and solute. (Hatschek) X The condition is a pure precipitation not a gelation. When a gel is formed the whole mass D.M. and D.P. becomes solid and no clear separation occurs. The D.P. certainly seems to be coagulated or precipitated in the substance of the gel but the whole remains in one mass. It has, as Ostwald states, become a heterogeneous microscopic state. In the case of casein Mathews describes the gelation as due to the formation of an insoluble precipitate which does not flock out of the solution but remains holding the liquid between the particles. This liquid will hold other substances in solution and will also consist of a saturated solution partly precipitated. Mathews explains the phenomenon by saying that the more liquid phase i.e. the D.M. is made solid by surface forces. He points out that at the boundary of two liquids the attraction of the molecules in the two directions outward and inward is different, so that in the surface layer the liquid molecules have their freedom of movement reduced. It is only necessary that the amount of liquid in the surfaces shall be large compared with the amount of liquid not under the action of unequal attractions.

X See also page 48.

In other words the proportion of liquid in the form of surface film must be sufficiently high. To get this, all that is required is a fine division of the precipitate, together with a concentration of the precipitate and an attraction between the precipitate and the solvent. If the amount of liquid is too great the particles will separate out. This theory corresponds in some respects with my suggestion that one factor of gelation as deduced from the action of electricity is the disappearance of water from between the particles whether they are ultramicroscopic or even smaller. In the case of the electric current I suggest that the two factors exist, the enlargement of the particles and the loss of water by electrolysis. The H and O H ions of the D.M. pass to their respective poles and become neutralised and ultimately the O and H elements become released as gas. At the same time the particles under influence of electric force become more hydrated and we get the condition of the surface films suggested by Mathews. As we saw previously the effect of the surface tension (positive) would be that there would be a tendency to subdivision if it remained at its original value, but the presence of the electric energy would lead to a decrease of surface tension, together with an increase in the expansile energy from the same cause. Therefore it appears to me one might get an expansion of the particles and at the same time a greater hydration, which, with the electrolysis, results in a decrease of the D.M. Thus:-

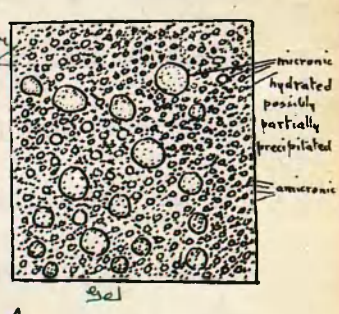


1
Particles amicronic and micronic. D.M. markedly present.



2
Particles expanded and hydrated.

3



4
D.M. removed by electrolysis. i.e. greater concentration of D.P.

It is necessary to make clear that I am here not discussing the question of the surface tension of the system as a whole. It is easily seen that if the surface tension of the whole system remained constant there must if volume is constant be a subdivision of the particles as a result of the expansive energy. The apparent paradox of an increase in size of the particles lies in the fact that to correspond with a lower surface tension in the system the individual particles must become larger. Here I am merely discussing the individual particle. A similar example may be found in the electrification of a soap foam. If one introduces electrodes and charges a bubble the bubble enlarges. To do this there must be a decrease of the surface tension, otherwise the bubble would burst. Again, in the case of the electrical action on serum the volume does not remain constant. It increases as well, as far as the D.P. is concerned, if the assumption of the constitution liquid + liquid system is correct as mentioned on p. 14. There is therefore attainable a comparative increase in concentration, for there is an increase in the number of particles relative to the volume of D.M. present. What happens essentially is a transference of the molecules of the D.M. to the particles from the D.M. excluding the molecules ionised and given off as gas. Ostwald in discussing surface tensions brings in the expansile surface energy and endeavours to show how the presence of expansile and contractile energy is reconcilable. As he states, when these forces are in equilibrium the particle remains the same size, but the introduction of, say, electrical energy into a system leads to an action and reaction of these two forces. This view has been already mentioned on p. 19. It is mentioned here in order to suggest that there might be present expansile energy in addition from electrical reactions. For example, the increase in the size of a bubble from an electric charge is explained under the electronic theory as very possibly

due to an accumulation of,say,electrons or at least ions of the same charge in the surface layer resulting in a repulsion between themselves,and hence the expansion. This will be referred to again. However that may be,the arguments applying merely to the action of surface energies of the system as a whole,do not necessarily preclude the actions and reactions of the individual particles and their surroundings. The two chief changes are,then,apart from the loss of water from the system as a whole,the taking up of the substances in the D.M. by the surface of the particles as Mathews describes,and the taking up of water by the particles themselves which as is seen would leave a system composed of practically no D.M. but all D.P. This is certainly different from saying,as Mathews does,that the D.M. is made solid by surface forces,but whether the precipitated matter is outside the original"envelope" of the particle or precipitated in it is of small account. The presence of"conglomerates"is accounted for by the actual coalescence of particles which are probably themselves gelated. This coalescence may also,as I suggested,occur in the formation of the larger particles under certain circumstances.

It is a little difficult to account for the formation of conglomerates when outside energy is added to a system. We have seen that if the surface tension is lowered there is an increase in surface. This of course would not occur if the surface energy itself was freed through any cause and transformed into,say,heat(P.16) but we are not dealing with such a case. The explanation probably lies outside the surface energy laws and in the condition and charge of the molecules of the surfaces of the particles in relation to the total charge of each particle. This will be discussed later. The fact that there can be a transference of part of D.M. to the D.P.and vice-versa makes it impossible to apply the laws of surface tension in the way that one could if the D.P. was a constant volume and the only alterations were

in the area of surface of the phase in question.

As to how the particles come to coalesce will be discussed later. The increase in viscosity is gradual because the D.M. is being gradually withdrawn through the causes mentioned. The final surface tension result will be complicated by the developement of the amicronic particles to micronic size. Thus although we get a lowered surface tension of the original D.P. through the introduction of external energy, yet we get this rise in viscosity.

This would only hold of course for the electrically induced gelation as the electrolysis removes the additional D.M. while the additional salts would probably be involved mostly in the surface layers of the particles. These particles might or might not be precipitated in their interior solutions which would tend to become more concentrated. At any rate there appears to be a precipitation as well as the setting or gelation.

Again, we have to deal with the setting of serum with heat, when with heat the viscosity is decreased, as we saw already. We would be assisted to a decision on the point by an examination of a series of slides taken during the application of heat to blood serum at the same time as the viscosity. Unfortunately it has been found impossible to examine slides under heat to any great extent. The serum when removed from the tube in which it was heated and transferred to a warmed slide became cooled, which meant that a sudden increase of the originally lessened viscosity took place before the slide could be examined . This cooling effect was noted even when testing the viscosity of heated serum.(see further Appendix A.) The heating of a slide under the microscope was

only found possible to a small extent,as there was risk of damaging the condenser dark-ground lens and the microscope oil immersion. The only slides therefore that were reliable at all were the slide at room temperature,a slide taken just as gelation was beginning at 140^0 Fah't,and a slide gelated by direct heat. The notes on these were as follows:-

Temperature	Viscosity	Slide
57^{0}Fah't	1·6	Particles fairly numerous,mostly medium to large medium. Brownian movement good.
a 98^0	1·05	Fairly numerous-more variety some large to very small. Brownian movement much the same.
142^0	? (Too viscid to run out of tube without pressure)	The penetration of light much less-marked conglomerates large and small. Particles large,medium and small, all varieties extremely numerous. Very slow Brownian movement.
b 144^0	Infinite.	Opaque-composed of a very great number of apparently precipitated particles. D.M. and D.P. indistinguishable.

a
Unreliable for reasons stated.
b
Produced by direct heat on slide taken at 142^0.

The transformation at the higher temperature to the gel condition is shown to occur in two stages with very different slides. It may be that the slide at 142^0 shows the precipitation of the one element of serum albumin,and the later slide showed the precipitation of the other elements and of globulin as well. Howell[3] certainly refers to others having described three separate coagulations of parts of serum albumin at 73^0 , 77^0, and 84^0 C. respectively. He further quotes a higher temperature for the first coagulation viz:- 158^0 to 167^{0}F, but he mentions that this point varies with the conditions. However this may be,the alteration by heat to this gel condition is a quite different phenomenon to that of precipitation by,say, saturation with Magnesium Sulphate when

the globulins are thrown down but the albumins remain.[3](See discussion on P.33 and P.42) •

Further on P.33 it is noted that the viscosity 1·43 showed the particles generally very small and numerous. It is difficult to reconcile that finding with this one when V = 1·05. The result of the slide being unreliable it is impossible to discuss adequately the possible explanation for the decrease in viscosity with heat. Heat added to a system lowers the surface tension,in which case one would imagine that the same result would be got as by electrical action . Between these two there remains the distinction that in the case of heat practically none of the D.M. is removed as gas until the temperature reaches a sufficient height. There is thus still a great distance between the larger particles,and the viscosit would therefore not necessarily show an increase. Further the introduction of heat into a system increases greatly the activity of the molecules,or at any rate of the electrons. The vibratory motion of these in the case of a metal may be increased so far that the vibrations create light waves and the metal becomes softer. Finally the viscosity decreases from infinite to the point of flow. In the case of serum,therefore,the explanation of the decrease of viscosity may be explicable on such grounds,and the molecules of the D.M. show less attraction to each other under the action of heat. After all phenomena generally depend on the nature of the transformation of energy whether the resultant energy takes the form of heat,or chemical,or electrical action. Chemical energy, for example,may give quite a different result from another form.

Again,if for reasons as yet unexplained the particles do coalesce to a certain extent with heat,as the slides seem to indicate the decrease in viscosity would be still more clearly reconcilable with the presence of conglomerates. It is clear,as has been

mentioned,that the result of the coalescence of particles would be a conglomerate of less surface than the original particles and there could quite possibly be a dehydration of the particles with a resultant increase of D.M. This would naturally decrease the viscosity up to a point when the dehydration ceased to compensate the loss of D.M. by evaporation and the viscosity would then rise rapidly.

We could thus find that the viscosity might be lessened, without the slide showing only small particles. When the heat reaches a greater height,the evaporation becomes more marked resulting in a rapid decrease of the D.M. and further chemical action comes into play leading to a precipitation of the substances present either in the D.M. or in the surfaces of the particles of the D.P. and we again get a gel. This precipitation action would reveal the presence of numerous small particles previously unseen.

Thus the addition of energy in the form of heat gives a different result from its addition in the form of pure electrical energy by means of the current,yet in many respects the processes are alike. The difference,which is evidenced by a gradual increase of viscosity in the one case and by the gradual decrease of viscosity to a certain point in the other seems to depend mainly on the result of the transformation of the energy added within the system itself. This transformation shows itself in the changes in the particles,in their coalescence,in the dehydration or hydration,and in the resultant relative amounts of the D.P. and the D.M. Thus with the electric current the electrical energy results in the removal of water from the D.M. by electrolysis with an increase of the D.P. relative to the D.M. through the coalescence of the particles and their possible dehydration, together with a decrease in the attraction between the molecules of the D.M. followed later by precipitation in the D.M.

or surface of the D.P. On the other hand the appearance of the slide just before gelation when the viscosity was increasing rapidly at 142^{0}Fah't was that of the slide observed under electrical action,and the question is whether at the point of change from decreasing viscosity to rapidly increasing viscosity there is not an extremely rapid generation of appreciable electric force resulting in an action or reaction similar to the previously discussed electrical gelation. Speaking generally this difference between the two is a result of differing relations between D.P.and D.M. due to the differing forms of energy. To reach a definite result for the whole matter it would be necessary to be able to calculate ultramicroscopically the comparative degree of dispersion and concentration. This for reasons given (Appendix B) was impossible for me to do during war.

There remains for discussion the changes in viscosity with time,with actions of acids and alkalies,on inoculation etc. To discuss these in terms merely of changes in surface tension is almost impossible and one is driven to seek the explanation more fundamentally. While one could discuss changes in the particles and degree of dispersion under outside agencies such as electric energy and heat,these do not arise where merely time is concerned. Nor can one merely reason about changes in surface tension due to the concentration of substances in the surface,without seeming superficial in one's arguments. One is driven to find a common basis for all these phenomena. The difficulties are obvious of explaining adequately the actions of such things as positive and negative surface tension,or contractile and expansile surface energies. Can one then find a more fundamental basis?

The basis of the actions and reactions of all matter seems to be in one way or other electrical. The electric current is not the only form of energy. The electron theory has shown

to a very large extent that chemical, temperature, and light energies are really electrical reactions. Much remains to be proved yet, but tremendous advances have been made. If we take surface tension, for example, we are involved in the problems of the two varieties. As we saw it is possible to resolve the expansile energy into the repulsion of ions or the larger charged molecules of the same sign. The contractile surface energy might be similarly resolved into the attraction of the neutral molecules for each other or the attraction of ions or charged molecules of the opposite sign for each other. If the latter is the case then the question of the number of ions of which sign will settle the whole question of the expansion or retraction of a surface film. For example if for any reason in a surface film the positive and negative ions are equally present per unit of area, then there will be a continuous attraction until they unite and form neutral molecules. These neutral molecules further possess an attraction for each other according to the elements of physics. It would be of no value to proceed in this paper to interpret the attraction of neutral molecules in terms of electricity. The interpretation is to be found in such a book as The Electron Theory (Fournier d'Albe)

That it is electrical is undoubted. Thus under certain electrical conditions there is a large positive surface tension. If, however, owing to any cause there should be an increase in the number of positive or negative ions it is easily seen that the relationship of the increase in the numbers of these will determine the degree of expansion, in other words an expansile energy comes into play. Now the presence of a charge of either sign in a particle will result in it becoming a conductor, and the laws of such things as spherical conductors apply. Conductors spherical in shape always act in such a way as to make their potential a

minimum and their capacity a maximum. The capacity varies as the radius. Further when two similarly charged bodies repel each other and move apart their potential is lowered and their capacity increased. As charged conductors free to move always move to make their charges a minimum and capacity a maximum, the tendency would be for such charged bodies to be continually repelled by each other. (Fournier) Thus one would imagine Brownian movement might be caused, for as we know the particles in a Colloid system all carry similar charges. Again, the change in size might be resolved under the above laws, as being a tendency of the particles to adjust their capacity to a minimum potential. The capacity would therefore again vary as the charge, for by expansion there is attained a lower potential. Thus the more free available charges for a particle, then the greater will be its tendency to expand, the expansive energy being presumed to act by the mutual repulsion of the charges present in the surface, for as we know a charged conductor carries its charge on its surface. As we saw the source of energy sufficient to cause a violent reaction was an electric current. This was the force necessary to cause the particles to assume a charge. Again, heat was another source. The result of these forces was an assumption by the particles of a charge. Now the addition of these outside agencies is not necessary to the assumption of a charge. The great function of water is that substances in it split into ions bearing a charge, as we saw at the outset of this paper. As we know, water forms the great proportion of the serum, and it contains substances which therefore tend to become dissociated and assume charges. In other words these substances either acquire an extra electron or lose an electron. The transference of electrons or particles of negative electricity therefore occurs.

We have thus reached a point when we see that the alteration in the size of the particles could follow from their electrical

condition,and that there may be created in the D.M. charged atoms or ions. There remains to endeavour to correlate these two facts. Can the state of the D.M. as to its charged contents influence the charge of the particles?

At this point we come to the modern definition of acidity and alkalinity. According to Howell[3] the acidity or alkalinity of a fluid is a function of the concentration of H or O H ions per unit of volume. When the H ion concentration exceeds the O H ion concentration the liquid is acid,and when the condition is reversed the liquid is alkaline. The H ion concentration × O H ion concentration = Constant. This constant is the dissociation constant of water for the given temperature.(Mathews) The question now arises as to how the particles get their charge and whether any relationship can be found between that and the ion concentration. While most calculations and references in the text books dwell upon the H ion concentration,from various facts it would seem that the blood serum is more concerned with the amount of difference between the two H and O H concentrations. As far as the blood serum in vivo is concerned it is not known whether the H concentration ever exceeds the O H,in other words whether there is ever any <u>real</u> acidity. To indicators there may be a change and of course if litmus is used there may be a relative acidity i.e. an increase in H ions above a certain point which results in the change in litmus. The result is that the terms acidity and alkalinity vary in their meanings at the present time. For example in H ion concentration greater than $N \cdot 10^{-7}$ litmus turns red,while phenophthalein is still colourless at that concentration and becomes pink at less than $N \cdot 10^{-8}$. As the blood serum is alkaline to litmus and acid to phenophthalein its H ion concentration must be between $N \cdot 10^{-7}$ and $N \cdot 10^{-9}$[4]. Now blood serum at about 18^0 C. gives an H ion concentration between $6 \cdot 10^{-8}$ and $2 \cdot 10^{-8}$. If the dissociation constant of water

at the same temperature is $.72 \times 10^{-14}$, then O H concentration would be 1.2×10^{-7} to 3.6×10^{-7} (Mathews). Now if one takes blood serum and raises the temperature from 18^0 to 38^0, there is only a slight alteration in the H ion concentration but an enormous increase in the O H concentration.(Henderson[4]) In a rise of temperature the O H change is therefore of most account. These facts assist in showing that the ionic concentration in the serum is of immense importance, and it can be shown that in some way it is related to the charge on the particles. This is shown by the fact that experimentally the acidity or alkalinity of the system determines the charge on the particles. Pauli[1] has shown that in certain substances removal of the electrolytes results in an entire absence of charge. At any rate the presence of electrolytes is the influencing factor in the reaction of the serum. If the fluid is alkaline in the real sense the particles carry a negative charge. If acid, they carry a positive charge. Acidity to litmus even to a marked extent does not alter the charge.(See p. 26) By a suitable addition of electrolytes however the charge can be altered[1]. Thus we see that the ion concentration, which is altered by the presence of electrolytes one way or the other, will affect the charge of the particles. Again, in the particles there is a greater concentration of the substances composing them at their surfaces. As the system is liquid + liquid, this concentration includes the presence of electrolytes . Thus in each part of the system there is present the necessary factor for a possible inter-change of charges between the particles and the D.M.

The actual manner of derivation of the charge of the particles is much debated. It appears to me that as has been put forward previously, the blood serum cannot be treated alone . Thus the influence of the presence of other elements of the blood, the

endothelial lining together with energy supplied to the walls of the blood vessels,and the factor of oxidation through the lungs must also enter. These factors again are influenced by other systems and organs. Hence there must be a great variety of sources of additional energy which may alter the ion concentration and affect the charge of the particles. It is however possible to consider one or two factors as a type of how alterations may occur. Taking the serum as a system containing D.M. and D.P. the latter being immense complex molecules of the system,there must be a balance between both these phases. In other words the entire system must be equalised as far as number of charges is concerned. If they were not equal in number then if one or other part contained an excess of charges the result would be quite unbelievable.Fournier describes in notes on dissociation that if in the dissociation of H and Cl in water that is,of two univalent substances,the ions of the one exceeded the ions of the other by one ion,the charge of the liquid would be at a potential of 100,000 volts.[5]

The ionic concentration of course is the result of dissociation in the medium of the electrolytes. Some substances dissociate more freely than others. If,for example,the proteins combine with an acid,the product dissociates few H ions.[4] The pure proteins are not electrolytes but their combinations with acid or alkali,for they can act both as acids or bases,are weak electrolytes. (Mathews) These electrolytes,the derivation and nature of which does not enter into our immediate consideration,are distributed between the various phases,and that part of them which is dissociated gives a number of ions containing opposite charges which balance each other. This dissociation as we saw,results in the difference of concentration of the ions. At the same time it would seem that the other side of the dissociation,the bases must be also present and as these bear charges must have a certain influence,although

apparently the H and O H element is the important one. We can therefore see that the dissociation may vary depending on the substances and their quantities in the serum. In other words the H and O H concentration is largely controlled by these electrolytes. As we saw on P 26 the effect of Sodium Hydroxide is enormous. This has been noted by Pauli and Handowsky also. They found with the addition of Sodium Hydroxide to serum albumin an increase in the concentration of O H ions is associated with a great increase in viscosity e.g.when the O H concentration was $1900 \cdot 10^{-5}$ the viscosity was increased 151% but when the O H concentration was $2805 \cdot 10^{-5}$ the viscosity increased 195%. As I showed, the normal solution of Sodium Hydroxide, which is much stronger than that used by Pauli, gave a very much greater increase up to very nearly the point of gelation. In that case I further showed that there was a marked increase in conglomerates, and in the variety of particles, and also in the total number relative to the D.M. for the conglomerates must have arisen from coalescence of particles and yet the general number of particles remained the same. (See P. 26) We have thus then a marked alteration in the particles with a change in the O H ion concentration and therefore in the difference between O H and H ion concentration, for their product = constant. Yet we saw that the addition of H ions as HCl increased the viscosity, although only slightly. There was a very slight change in the slides but not sufficient from which to judge or discuss the change. Here there cannot have been an increase of O H ions. The assumption to which one is driven is not that the increase of O H ion concentration alters the particles in one direction and that increase of H ion concentration alters it in another direction but rather that it is a change in the balance of the two that is present when the particles alter. As the serum is alkaline to begin with, it is natural that the addition of O H ions i.e. a greater increase of

the already marked excess, should cause a more marked effect.

As we have seen, the electrolytes are the balancing factors and are present in both particles and medium. The change in ion concentration can be resolved into the exchange of electrons. The alteration in surface of the particles with all the inter-relations of surface energies, can depend on the transference of charges either strengthening, as in addition of O H ions, or weakening the charge to the point of alteration by the addition of H ions.

Further, the concentrations of electrolytes in a surface may lower or raise the surface tension, the result depending on the nature of the electrolytes. (Ostwald) If we consider the surface forces in terms of attraction or repulsion of molecules or smaller bodies, we can see that an alteration, as it were, of the permeability of the surface of the particles is possible. Further, electrolysis has shown the variation of the mobility of ions and has led to a conclusion that their degree of hydration varies with the nature of the ion. (Fournier)

If we turn to the gel state for the moment, we find, from Hatschek, that gels imbibe water, but that the gel plus the water imbibed is a lesser volume than the separate gel plus water. The water has been compressed. He further shows that the alterations in viscosity which have been described by Hoffmeister in his famous series,[1,2,4] and which have led to very great discussions on the valency properties of substances in this regard[4] can only be explained by the general fact that the salts of the Hoffmeister series affect the compressibility of water, and thus alter the inter-change between the D.P. and D.M. of water. In other words, electrolytes affect the hydration and dehydration of the particles. It would seem to be that there is a relation between this fact and the depression of ionisation by the introduction of a common

ion,a well known phenomenon. One can imagine that the electrolytes may influence the number of H and O H ions actually derived from the water element of the system. Further,the more water is itself ionised the greater may be it's power of permeation and transference The variation in the surface of the particles allowing of change in permeability depending on the amount of repulsion or attraction between the bodies present in it would therefore play a great part in the hydration and dehydration of the particles.
The tremendous increase in conglomerates and the rapid increase in viscosity with Sodium Hydrate inclines one to this hypothesis.

Again,if we consider the fact that some colloids of opposite signs precipitate each other we find a further strengthening of our theory. The formation of conglomerates,as we saw,is probably due to the coalition of particles. A passing point of interest is that some of the smaller conglomerates have been noticed by me to show a very similar dark ground appearance to lencocytes only much smaller. They showed the long mobile off shoots that one frequently sees in lencocytes in dark-ground slides[4,13] and which have been mistaken by some for spirochaetes.[13] These particles can only coalesce when their"envelopes"actually come in contact,if not the actual surface. How the particles come in contact is a matter for discussion. Some suggest a neutralisation of sign as is supposed to happen when colloids of opposite sign precipitate each other. Ostwald suggests this, but if this is so then the addition of alkali to an already alkaline system,cannot alter the charge,yet there are conglomerates formed. Also I have found small conglomerates to possess a charge the same as the particles in the same film. Once the close contact is attained the surface forces bring about the coalescence Bemmelen suggested that a tear occurred in the surface film thus

allowing contact. These matters will require to be left undecided meantime. There may be a change in the concentration of electrolytes in the surface resulting in the presence of neutral molecules whose attraction balances the charge and thus allow the molecular attraction between the particles to act.
The electrolytic force might still induce the conglomerates to assume a further charge for itself as a whole. There also remains unsolved the reason why the particles acquire a negative charge when the O H ion concentration exceeds the H . It may be that they tend to take up electrons to keep the actual concentration in the D.M. of O H and H more equal. In other words,they may act as a regulating factor in the ion concentration of the blood as a whole. It would be of great interest to ultra-filtrate the serum and subject it to many of the tests which have been done with the whole serum,with at the same time ion concentration calculations. The general ionic concentration may largely depend on the particles therefore,but whichever is the most important element,there is little doubt that the D.M. and D.P. are interdependent and interchangeable,and that their inter-reactions involve the transference of electrons.

Now this transference of electrons is simply the phenomenon of reduction and oxidation. A substance losing one or more electrons according to its valency is oxidised,while the substance acquiring it or them is reduced, The terms are unfortunate. In other words,the substance which easily acquires one or more electrons is an oxidising substance. Oxygen does this, but so does many other substances. The carbonic acid molecule tends to lose one and is therefore a reducing agent. Now if we turn to the blood serum we find that the particles in virtue of their ability to increase their electro-negative charge in

alkaline serum are oxidising agents. If the serum were ever to become acid to the extent of H ion concentration exceeding O H ion concentration the particles would cease to be oxidising agents, as they would tend to lose electrons and become positive. One cannot help wondering whether the "air-hunger" of acidosis in Diabetes mellitus is not explicable along this line,following as it does on the presence of B-oxybutyric acid in the blood. The particles in this case tend to be less active oxidising agents.

In relation to the possibility of the particles being oxidising agents,it is interesting to remember that the lencocytes themselves are very active oxidising agents,or at least their contents are. When one remembers that the substances in them,as in other forms of cell protoplasm,are in a colloidal state it increases the interest. I remember when in my Final year while taking lectures on Clinical Pathology under Dr.John Shaw Dunn he showed us some phials of extract of leucocytes which he had made two or more years previously during his experiments on the oxidase reaction staining. Even after that lapse of time the extract showed,as we tested for ourselves,that it was a powerful oxidising agent. The thought comes to me that the nature of the colloidal particles present in the cell may also account for this power of oxidation. That the cell which is in a colloidal state should show such marked power is somewhat significant.

I would make clear that I do not infer that all particles in a substance in the colloid state are oxidising agents. My suggestions are intended to apply to blood serum only. It is obvious that if the particles were of positive sign,that is,tend to give up more and more electrons while their positive charge increased,then they would be reducing agents. This is a point well worth further investigation,but does not concern the present paper.

If there is anything in the above theories, it would seem that we are at the outskirts of an immense field in practical medecine. The question of how far experience can back up these theories arises. My investigations have been devoted largely to this attempt to suggest that the findings of many eminent physico-chemists for colloids apply in some measure to blood serum, but at intervals I have been enabled to look at a few slides in different conditions. In syphilis, for example, which I am at present investigating in this respect, there is no doubt whatever of the profound alteration in size and degree of dispersion of the particles. M'Donagh of London whose theories are the cause of much antagonism and derision from some quarters, describes these variations.[10,12] I do not find his results tally with my observations altogether but many do. He, again, has raised this question of the influence of the particles in relation to anaphylaxis and surgical shock.[11] I have to confess that I could not follow his argument on the subject, yet I was deeply impressed by observed alterations in the particles in syphilis. I therefore took up this investigation from a different starting place, the physico-chemical investigations of allied substances and it has led me to the results of this paper.

In syphilis at different stages, I have seen for myself profound alterations. In serum inoculated with other serum variations occur. In high fever I have seen changes, and I am hoping to accumulate evidence over a sufficient number of cases of different kinds to support my contention.

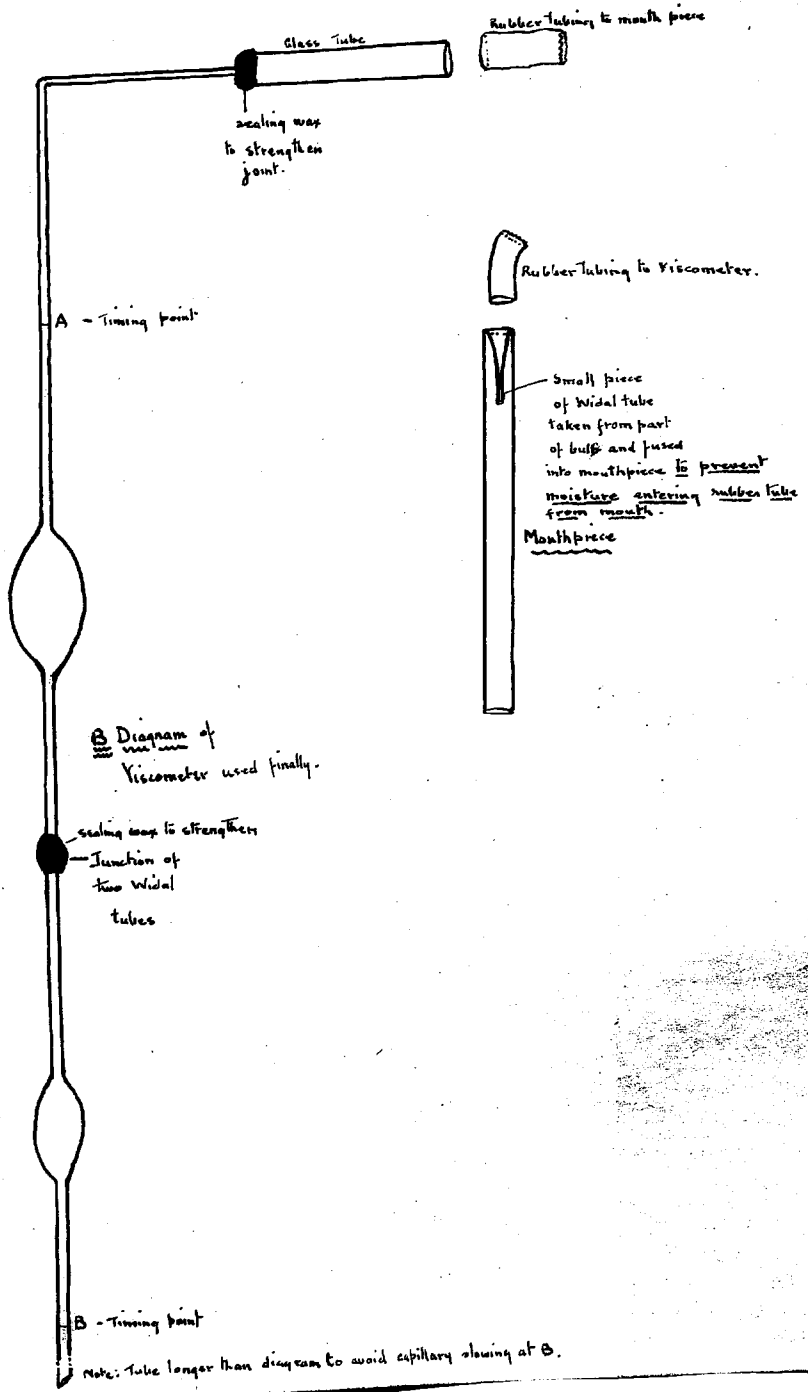
I have said enough to show the possibilities. Already the realisation of the colloidal state has led in the direction of the solution of such problems as muscle contraction,[1] has enabled inorganic colloids to be made which closely resemble organic

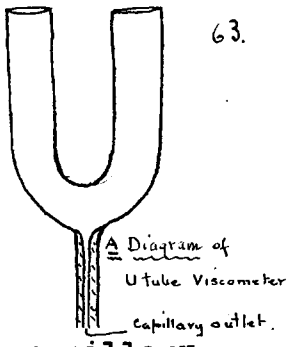
ferments in their action. It has thrown light on the imbibition by the cell of water and on the nature of the cell itself. It has led to further light on electrical reactions in the body, and to many of the phenomena of plant life. It will repay much study and it is full of intense interest.

Lastly, in colloidal drugs we have a new adjunct to medecine. There is much discussion about these, and great difference of opinion. My personal experience is not extensive enough to quote. One has to buy for oneself such drugs for use in the service. One would venture to think that in their close likeness to the general body fluids they will be found of greatest value. I certainly know of the results of Collosol Iodine and Sulphur.

One has thus reached the culminating point of this paper, and one would finish with the query which inevitably arises in one's mind:- If there is anything in these findings; if there is any truth in this question of the relation of the difference between O H concentration and H ion concentration in the blood and changes in the body, does not a new opening for investigation lie open to us, and may not treatment follow the line of an attempt to find the abnormalities in these conditions, and to restore, by the corresponding colloidal drug, the normal condition for correct oxidation and reduction in the body.

While these latter pages are theoretical for the most part, yet behind the theories are ascertained facts which direct attention to the importance of the colloidal state of the blood-serum and its electrical reactions.


Glass Tube
Rubber Tubing to mouth piece
sealing wax to strengthen joint.
Rubber Tubing to Viscometer.
A - Timing point
Small piece of Widal tube taken from part of bulb and fused into mouthpiece to prevent moisture entering rubber tube from mouth.
Mouthpiece
B Diagram of Viscometer used finally.
sealing wax to strengthen
Junction of two Widal tubes
B - Timing point
Note: Tube longer than diagram to avoid capillary slowing at B.



A Diagram of U tube Viscometer

Appendices giving Details of Apparatus etc.

Appendix A.

Experiments on Viscosity.

(1) The instrument first tried was a U tube with a capillary out-let as in diagram. After a prolonged trial this was given up, as the size of the U giving the best result was too great for the supply of serum. In the smaller one, the opposing surface tension of the drop at the end of the capillary checked the serum too soon and irregularly in the U and the timing was too variable over the same distance with water.

The best results were finally got with two Widal tubes fused together in a spirit flame. (See Diagram B.)
This gave a rough copy of a viscometer shown in Ganot's Physics.[8]
The two tubes when fused together were tested for clear passage way and air tightness and the junction covered with sealing wax to strengthen it, as the slightest tap broke the junction. The end was fused into a larger piece of glass tubing and the joint protected by sealing wax. A great many had to be made before an air-tight joint was got, as with the slightest opening at the joint the sealing wax was dissolved in the ether in the tube for cleaning and spoilt it. Frequent breakages required new tubes but they were all tested in the same way, with great care. They were marked at a sufficient interval for timing.

(2) The standard taken was distilled water. This was distilled daily on board and was very clear and good.

(3) The experiment was conducted as follows:-

Each time a viscosity experiment was done the water standard was taken. This was found necessary owing to the breakage and renewal, and also owing to variation in my reaction time. After continued practice with water and serum, I found myself

sufficiently trained to get reliable comparisons. I then found that during the time of one or two experiments my reaction time remained steady, and the water standard was always the same. It was only occasionally, if the same tube was used, that the time varied, and then it held good for all the time of the experiment. In other words, at one time time of day the standard might be longer by stop-watch but that variation was constant for the time of the experiment as proved by constant re-checking with water. This occured rarely, and only if I was a little tired by exercise. Usually, for the same tube, the time was constant day after day for water.

In doing the tests the tube was always made wet with the material to be tested, as the tube was always made perfectly dry between each test. This was a precaution against any alteration due to outside substances. The wetting of the tube was necessary as the substance was apt to be unequal in flow the first time.

The routine was to carefully draw up into the tube the fluid to the upper mark and then to let it run out back into the fluid with the point of the tube in the fluid. This was unfortunately necessary owing to the scant supply of serum. However, every test was done in exactly the same way, and any decrease in viscosity due mechanically to a small portion of serum being drawn into the tube and run out was the same, as it was only done once and the second time the test was made. Where owing to a slip the fluid had to be drawn up more than twice, it was noted in the fig. in question. Very occasionally I took the average of two times if one raised doubts in my mind as to my speed in pressing the stop-watch, or as to the position of the tip of the tube. In all experiments when timing was done the tip of the tube was held against the side of the test tube or glass which had the serum or water in it. This was found to give the best uniform flow

for timing, as drops did not form and give a jerky flow, as when the viscosity tube was allowed to drip.

(4) After each test, the tube was cleaned with distilled water, alcohol and ether, until it was clean and perfectly dry. It was considered better not to use salt solution for fear of it affecting the serum test in any way.

(5) A Naval gunnery stop-watch was used, and the viscosity in the figs ~~were~~ was expressed in the time of serum to the time of water to flow past two fixed points in the tube.

(6) The Temperature was noted by a Thermometer kept in the tube-rack. This Thermometer showed large variations and was borrowed from the Engineering oil testing room. The cabin in which the tests were done was small and the temperature variation was very slight over long periods and uniform over the time of testing.
Before starting each time the cabin temperature was adjusted to the temperature shown in my results, through a judicious use of an electric radiator and the scuttle or ventilator. If ever there was any unnoticed variation it could never have been more than one degree Fah't above or below the standard.

(7) The Heat and Viscosity tests were carried out similarly, except that the serum tube was suspended in a tobacco tin heated by an electrical resistance wound round it and covered with asbestos. The Thermometer was placed in it and kept clear of the metal side by a piece of wood to prevent the metal contact raising the thermometer above the water heat. In this case the serum was drawn up twice and kept in to heat the tube, but the third time was allowed to run out immediately it had been drawn up for the reading, as holding it even for a few seconds reduced the temperature and increased the viscosity.

(8) For the electrical viscosity test see Appendix C.

View of Cabin Table with Apparatus.

size of Cabin 9ft x 6ft.

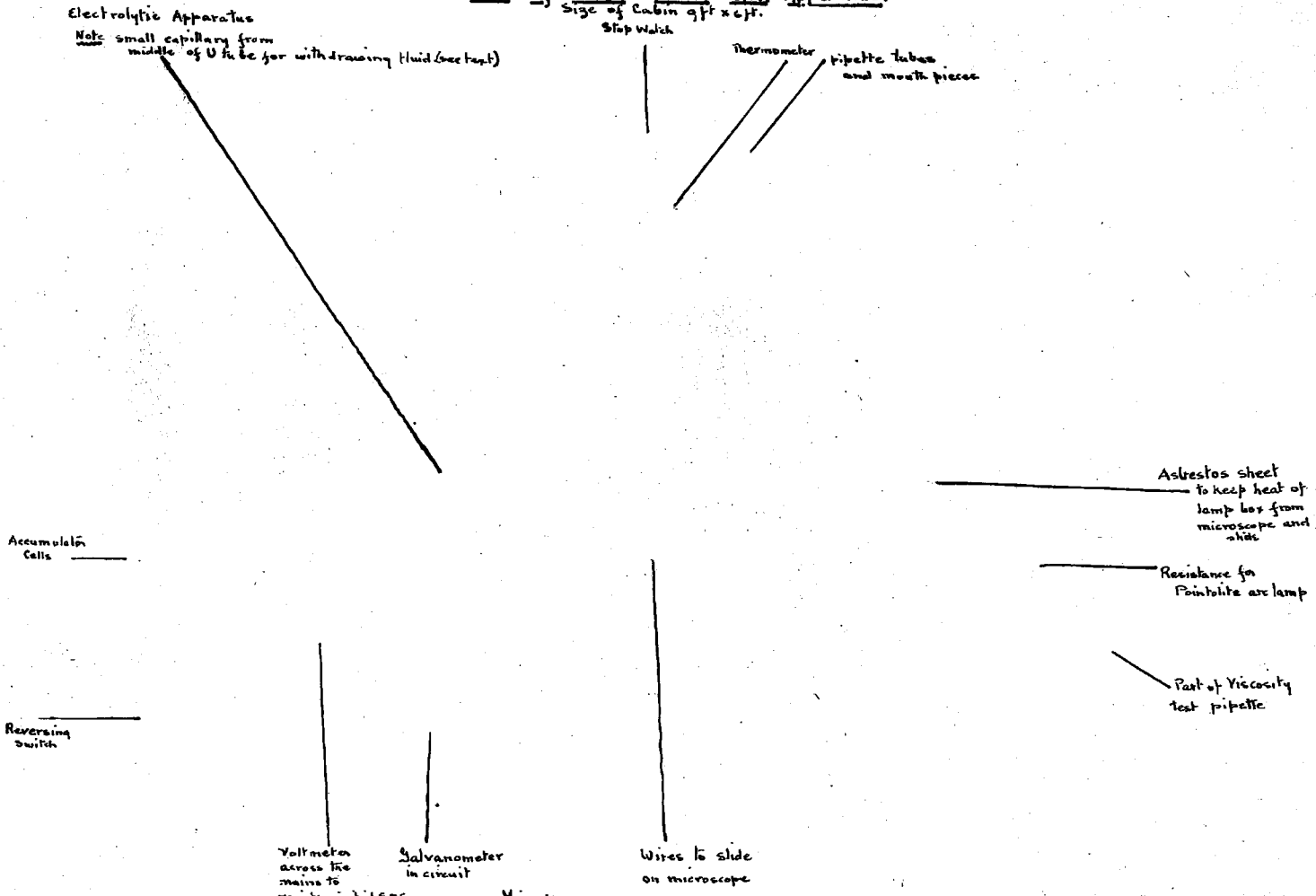


Fig. 11

(Photo taken by Sick Berth Steward Stirk)

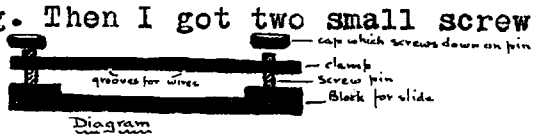
Appendix B (See Fig.11)

Electrical Experiment on the Microscopic stage.

(1) The Apparatus was as follows:-

It was at first necessary to get a slide suitable for the purpose. When on leave I had tried to get one with platinum wires fused on it without success. One of this description is described by Hatschek for testing gold sols. I had therefore to attempt to make a suitable arrangement instead.

I got two bacteriological platinum loops when on leave and these I got beaten flat at a silver-smith's. On board I got them fused to thin copper wiring, and attempted to fix them to the slide with Canada Balsam. This failed after several attempts, as they always came loose on cleaning. Then I got two small screw ebonite clamps made as per diagram



Diagram

With these I clamped the wires to the slide. With this arrangement I worked for some time, but the very slight spring on the wires raised the glass cover too far and made focus difficult and the capillary attraction between wire and slide drew the serum away from the centre of the slide and broke contact. This I attempted to check by vaseline with success, it being a non-conductor, but the wires were always slipping and unsatisfactory.

I then attempted to have the wires fused to the slide without success, there being no bunsen or glass blower on board. The slide was apt to crack and loose shape. Finally I had a very satisfactory slide made with the help and advice of a working optician found amongst the crew. He bored a slide for me with a fine drill in four places far enough apart to be outside the cover slips. Then he grooved the slide with a file between two pairs of holes and threaded the wires through from below along the parallel grooves on the surface and down through the remaining holes.

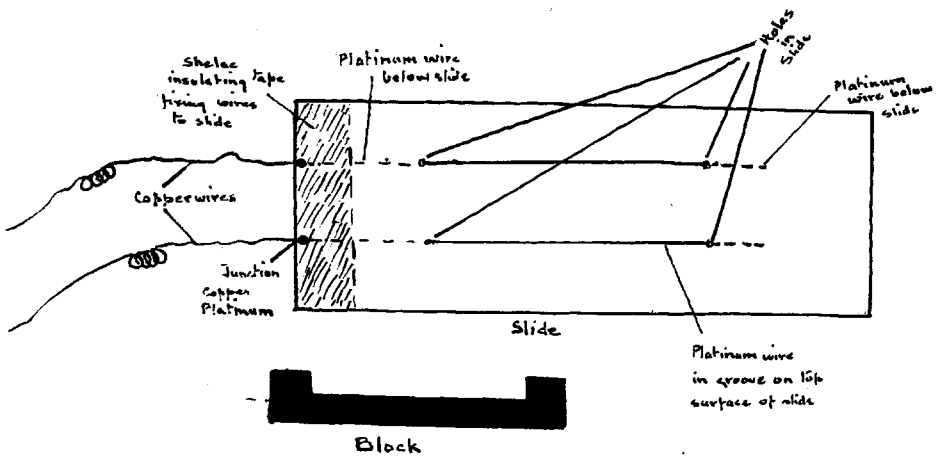

Shellac insulating tape fixing wires to slide
Platinum wire below slide
Holes in slide
Platinum wire below slide
Copper wires
Junction Copper Platinum
Slide
Platinum wire in groove on top surface of slide
Block

Fig 12.

The wires fused to thin copper wire leading away were insulated by shelac and silk tape,and I had two small ebonite blocks made of different thicknesses to make the slide perfectly level on the stage,which was impossible without blocks owing to the difference of level at the ends from the presence of the underneath wires at one end. (Fig.12)

My E.M.F. I got from two small accumulators,after calculating the approximate resistance through serum across the slide with a Wheatstone bridge instrument. The output of the accumulators was checked by a voltmeter each time they were used. It was absolutely constant. I had a small reversing switch in the circuit and a galvanometer. I had no mille-ampmeter on board,so had to calculate the current from the angle of the galvanometer which was a Gunnery testing Tangent Galvanometer of a 1000 Ohms,and fairly sensitive. I had hoped to be able to test the resistance of various sera but the result with the galvanometer was not sufficiently accurate. I hope soon to have an arrangement to do this,but not in time for the present paper. There are many factors to be eliminated for results to be of value,and their gradual elimination is a matter of time.

I had hoped also to calculate the charge on the particles, as Hatschek describes for metallic sols,but for this I found the viscosity of the D.M. must be found and that was impossible without eliminating the particles by ultra-filtration. Later I hope to try this. Given the distance between the electrodes and the potential drop,the calculation is quite feasible if viscosity is known. In metallic sols the viscosity of D.M. can be taken as water but not in serum without proof.

I got the distance over which the particles were timed by a micrometer eyepiece,and found the actual distance for a certain

position of the microscope with the same lenses by super imposing the image of the micrometer scale on the image of a blood counting slide. I attempted to measure the particles on a blood count slide with a view to measuring the comparative degree of dispersion, but the Thoma slide is not cut sufficiently deep to give the necessary reflection with dark ground. The lines only show in places, and the depth is an added difficulty for accurate counting. I believe it might be quite possible with a slide cut evenly and with the marking on the ordinary surface of a slide.

The micrometer eyepiece with the necessary calculation for magnification would do, but the markings would need to be to smaller distances. The account of these failures is given to show the possibilities of future experiment, for the degree of dispersion is quite as important as the size of the particles. After war it might be possible to get the necessary slide made.

(2) The experiment revealed the following facts:-

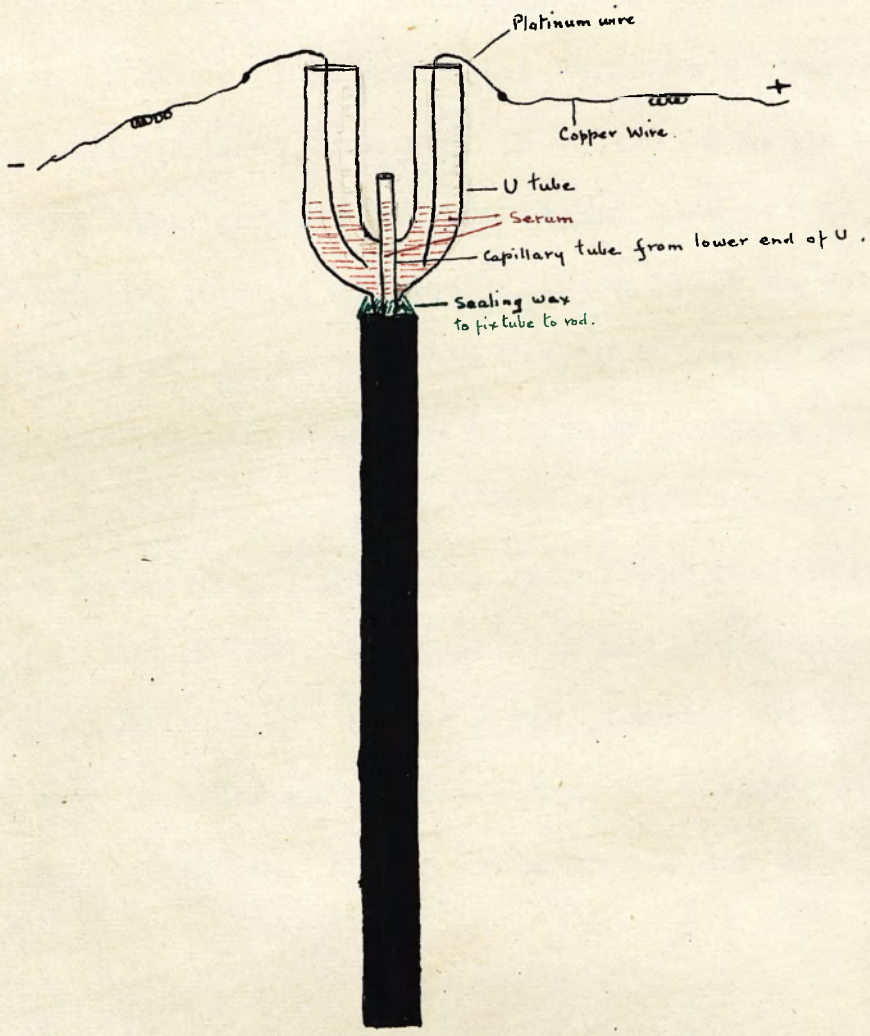
Under a slide polarization rapidly cut down the current. That it was polarization due to formation of gas was proved by removing the cover slip and passing the current after removal from the microscope. The macroscopic electrolysis (Appendix C) showed this was right. The consequence of this was that the timing of particles at different moments differed. This was the main reason for doing the counts at short intervals, and only counting where possible a large, medium and small particle in the one count. (See Fig 10.)

The drop in current was, however, not great enough to account for the slowing of the particles which was due mainly to increase in viscosity, for even when movement both Brownian and directive had ceased, the current still passed. The drop due to polarization is shown thus:-

Time	Galvanometer angle θ
Start	76^0
8 min	65^0
$8\frac{1}{2}$ "	61^0
9 "	61^0
$9\frac{1}{2}$ "	59^0
10 "	58^0

by which it will be seen that there is an increase in resistance. With a correctly adjusted galvanometer it would be simple to compare the resistances[7] of different sera with, say, distilled water as standard, as has been suggested. The reading would have to be taken immediately on first switching on the current because of polarization.

The directive effect was checked by the reversing switch in case any movement should be due to convection currents or other causes. The poles were always tested with litmus.[6] There was therefore not the slightest doubt that the particles remained electro-negative even when the serum was acid to litmus. The reason why the larger particles which probably had a larger charge (See text) did not travel more rapidly is explicable on the basis of hydration, and that they also had larger envelopes to drag along with them.



Apparatus for Electrolysis.

Fig 13.

Appendix C.

(1) The instrument was a small U viscometer as mentioned in Appendix A The capillary outlet I kept on the tube but heated it and twisted it round,giving the final appearance.(Fig 13) The advantage of this scheme was that I could withdraw the serum for slides,without taking it from either end. Being continuous with the U any alteration from the electric current was bound to be reflected in the side piece while at the same time there were no bubbles of gas to make difficult the removal of fluid by a capillary pipette and the making of a slide free from gas. One could pass the capillary down the side tube right into the main body of the U tube. The idea worked splendidly .
The current was the same as in Appendix B and was from the same source In this case owing to the free access of air to the tube,there was practically no drop in the galvanometer as the gas was able to escape. The electrodes were two platinum wires from bacteriological loops, soldered to thin copper wire. Even when the material had become gelated the current still passed freely which confirmed my decision mentioned in Appendix B,that the actual increase in viscosity was the cause of the slower movement,and not polarization.

Appendix D.

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University of Glasgow.

LIST OF DEGREES

CONFERRED ON 22nd APRIL, 1919.

DOCTOR OF MEDICINE (M.D.).

William Ernest Boyd, M.A., M.B., Ch.B.—*Thesis*, "The Colloidal State of the Blood Serum and its Electrical Reactions."

DOCTOR OF SCIENCE (D.Sc.).

David Burns, M.A., B.Sc.—*Thesis*, "On the Physiological Significance of Guanidin, especially in its relation to Creatin-Creatinin Metabolism"; with other papers.

BACHELORS OF DIVINITY (B.D.).

David Gordon Carmichael, M.A.
James Kellock, M.A.

BACHELORS OF LAWS (LL.B.).

Robert Dunlop Allison, M.A.
Colin Frederick Forbes Robertson, M.A.

BACHELOR OF LAW (B.L.).

Gavin Boyd, M.A.
William Thornton.
Thomas Watson.

BACHELOR OF SCIENCE (B.Sc.).

In Pure Science.

Elsie Doris Isabella Bertram.
Ethel Catherine Cameron.
Marjorie Celestine Holmes.
Minnie Cook Scouller.
Richard Sangster Shankie.

In Engineering.

[1] Osman Fahmy.
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Malcolm James Grange.
Otto John Hansen.
Leonidas Michail Kazezoghlou.
Anastase Kypriotis.
Alexander Paterson Laing.
Alexander Simpson Macdonald.
[1] Alexander Elsden Martin.
Olav Maseng.
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Tor Sætre.
Robert Lewis Scott.
Sheikh Mohammed Shariff.
Sheikh Mohammad Siddique.
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John Howat.
Robert John Liddle.
Helen Ireland McBroom.
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[1] With Special Distinction in Engineering and Drawing.